Final Report of the

Fourth Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean

January 2017

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List of Acronyms and Abbreviations

1D	One Dimensional
3D	Three Dimensional
ADCP	Acoustic Doppler Current Profiler
AZFP	Acoustic Zooplankton and Fish Profiles
C	Celsius
CAFF	Conservation of Arctic Flora and Fauna
CAO	Central Arctic Ocean
CG	Coordination Group
cm	Centimeter
CO_2	Carbon Dioxide
CPUE	Catch Per Unit Effort
CTD	Conductivity, Temperature, and Depth
DBO	Distributed Biological Observatory
EBFM	Ecosystem-based Fishery Management
eDNA	Environmental DNA
EEZ	Exclusive Economic Zone
ESS	East Siberian Sea
FDA	Food and Drug Administration
FiSCAO	Fish Stocks in the Central Arctic Ocean
ha	Hectare
IARM	Inventory of Arctic Research and Monitoring
IASC	International Arctic Science Committee
ICES	International Council for the Exploration of the Seas
IEA	Integrated Ecosystem Assessment
JSRMP	Joint Scientific Research and Monitoring Plan
kg	Kilogram
km	Kilometer
LME	Large Marine Ecosystem
m	Meters
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
mt	Metric Tons
NBC	Northern Bering-Chukchi Seas
nm	Nautical Miles
NPFMC	North Pacific Fishery Management Council
PACEO	Pacific Arctic Climate Ecosystem Observatory
PAG	Pacific Arctic Group
PAME	Protection of the Arctic Marine Environment

pCO_2	Partial Pressure of Carbon Dioxide
PICES	North Pacific Marine Science Organization
QA/QC	Quality Assurance/Quality Control
SAON	Sustaining Arctic Observing Networks
TAC	Total Allowable Catch
ToRs	Terms of Reference
U.S.	United States
USA	United States of America
WG	Working Group
WGICA	ICES/PAME Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean

Executive Summary

Future international management of potential fisheries in the central Arctic Ocean (CAO) has been addressed at a series of meetings of governments beginning with an initial meeting held in Oslo, Norway in June 2010, and continuing through the most recent meeting of managers held in Torshaven, Faroe Islands, Denmark, in November-December 2016[1]. Of particular relevance to these meetings has been the interest by the governments in the development of a joint program of scientific research and monitoring to inform future potential fisheries management in the CAO. This led to an initial scientific meeting held in Anchorage, Alaska, USA, in June 2011. The general conclusion of that meeting was that there was no urgency, but, given the limited scientific knowledge of the CAO, there was a need to establish baseline data. Additional scientific meetings were held in Tromsø, Norway (October 2013) and Seattle, USA (April 2015). Participants at these meetings developed a status & gaps report, a partial inventory of research & monitoring, and a draft framework for a Joint Program of Scientific Research & Monitoring. The report from the first scientific meeting (June 2011) noted: “Within the Arctic, current information on distribution and abundance of concentrations of these species, uncertainty in the ecosystem effects of fishing, and the technical and logistical challenges of conducting fishing operations in remote regions all suggest that commercial fisheries are not likely to emerge in the short term.” The report from the second scientific meeting (October 2013) further emphasized that demersal fish or shellfish are not expected to expand into the deep basin of the Arctic Ocean. The report from the third scientific meeting (April 2015) upheld the initial conclusions from the former meetings.

Following the adoption of the Declaration Concerning the Prevention of Unregulated High Seas Fishing in the Central Arctic Ocean among the five Arctic coastal states in July 2015, government representatives met in Washington, DC, USA, in December 2015 to further discuss management of potential CAO fisheries. These participants provided additional guidance on the development of a Joint Program of Research and Monitoring to address the following questions (which represent a refinement of questions raised in the 3rd scientific workshop held in April 2015):

- What are the distributions and abundances of species with a potential for future commercial harvests in the central Arctic Ocean?
- What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?
- What are the likely key ecological linkages between potentially harvestable fish stocks

[1] The meeting in Torshaven occurred after the scientific meeting in Tromsø.

of the central Arctic Ocean and adjacent shelf ecosystems?
- Over the next 10-30 years, what changes in fish populations, dependent species, and the supporting ecosystems may occur in the central Arctic Ocean and the adjacent shelf ecosystems?

To answer these questions, the representatives agreed to three Terms of Reference (ToRs) for the fourth scientific meeting:

- ToR 1: Complete the synthesis of knowledge
- ToR 2: Develop a draft Joint Scientific Research and Monitoring Plan to address the four questions
- ToR 3: Provide a Framework for the Implementation Plan

In response to the manager's request, Norway hosted the Fourth Scientific Meeting on CAO Fish Stocks in Tromsø, Norway, during 26-28 September 2016. In total, 29 participants attended the meeting representing 10 governments (Canada, People's Republic of China, European Union, the Kingdom of Denmark in respect of Greenland, Iceland, Japan, the Republic of Korea, the Kingdom of Norway, Russian Federation, and United States of America) and interested bodies, including the Arctic Council (Protection of the Arctic Marine Environment [PAME]/Conservation of Arctic Flora and Fauna [CAFF]), North Pacific Marine Science Organization (PICES), International Council for the Exploration of the Sea (ICES), and the Pacific Arctic Group (PAG). The participating scientists and others were all familiar with Arctic science, surveys and modeling, and the science necessary to support management and conservation of marine living resources.

With respect to ToR1, prior to the meeting, participants collected existing data and analyses of the CAO available from science organizations of the parties. This data call allowed for the completion of the synthesis and integration of analysis of "where we are now" and identified the priorities for research and monitoring gaps. Thus, on Day 1, participants discussed a draft synthesis report. Meeting participants provided suggestions for the collection of additional information, which are incorporated into the final synthesis report (Appendix B here). The discussions also noted that because of the low productivity associated with a seasonal sea ice cover and the associated strong vertical density stratification, fish densities of commercial interest are not likely to occur in the High Seas in the near future. However, participants also emphasized that baseline information, ecosystem understanding, and monitoring to detect future changes are important issues for the High Seas region.

The primary objective of the meeting was, however, to focus on developing a Joint Scientific Research and Monitoring Plan (Plan) to address the four questions (ToR2). A draft version of the Plan was prepared prior to the meeting to elicit discussion. This draft Plan built upon the outcomes of the previous three scientific meetings and considered the need for additional modeling of ecosystem relationships for areas of the CAO with physical and biological data relating to commercial fish species. During the meeting, participants broke into three groups (Mapping and Monitoring, Ecosystem Considerations, Scenarios to deal with Climate Change) to further develop the draft Plan. Meeting participants spent most of Day 2 and the morning of Day 3 in the discussion of these three topics.

Participants at the meeting used the discussion of the Research and Monitoring Plan (ToR2) to develop four Tracks as a framework for implementation of the Plan (ToR3): 1) Mapping and Monitoring, 2), Reference Points and Indicators, 3) Modeling and Scenarios and 4) Coordination. The first three tracks identified here specifically address ToR2, and provide guidance to a 2017 workshop (the 5th scientific meeting). This 5th meeting will develop an implementation strategy for the Plan, showing staged development of research and monitoring that addresses gaps in abundance, distribution, and other information providing advice about the potential for sustainable harvest of commercial species in the CAO.

Discussion of the Coordination track focused on how to implement the Research and Monitoring Plan through means other than biennial science meetings. This discussion provided some of the substance to define Terms of Reference for a coordinating body.

Meeting participants also discussed the issue of “exploratory” fishing (also referred to as experimental fishing by many of the participants). Many of the participants raised concerns about the damage that could occur as a result of exploratory fishing if it is conducted before we have more scientific data about the region, especially the bottom conditions. Some participants suggested defining parameters in the Research and Monitoring Plan under which exploratory fishing could occur.

I. Introduction

The issue of international management of fisheries in the High Seas of the central Arctic Ocean (High Seas; CAO) was addressed at a meeting of governments of the coastal states to the High Seas (Canada, Norway, Greenland/Denmark, the Russian Federation and the United States) held in Oslo, Norway, in June 2010. A key question raised in that meeting was "*what is the status of science?*" This led to an initial scientific meeting held in Anchorage, Alaska, USA, in June 2011. The general conclusion of the 2011 scientific meeting was that there was no urgency, but that given the limited scientific knowledge of the High Seas there was a need to establish baseline data.

The five governments next met in Washington D.C., USA, during April-May 2013. A key question raised there was "*what were the prospects for commercial fisheries in areas of the CAO beyond national jurisdiction*"? Again this meeting of policy makers was followed by a 2nd scientific meeting held in Tromsø, Norway, October 2013. The general conclusion of scientists in attendance was that there was no near term prospects for commercial concentrations of fish but there remained a need to know more about fish stocks with the potential to be harvested in the High Seas.

The next meeting of the five governments was held in Nuuk, Greenland, in February 2014. The governments reached elements of agreement on High Seas' fisheries, resulting in the Declaration Concerning the Prevention of Unregulated High Seas Fishing in the Central Arctic Ocean of 16 July 2015 among the five Arctic coastal states, which calls for a Joint Program of Scientific Research and Monitoring. The governments developed terms of reference at this meeting for the 3rd scientific meeting, which was held in Seattle, Washington, USA, in April 2015. At the 3rd scientific meeting, participants developed a status & gaps report, a partial inventory of research & monitoring, and a draft framework for a Joint Program of Scientific Research & Monitoring[2]. Participants at the scientific meeting identified several next steps, including the need for:

- A thorough synthesis and integration of analysis of "where we are now";
- Large-scale and coordinated monitoring, as possible, to capture temporal and spatial variability; and
- Continued development of an international Joint Program of Scientific Research and Monitoring.

The Declaration Concerning the Prevention of Unregulated High Seas Fishing in the Central Arctic Ocean envisions a broader process, and, in December 2015, the five governments of the coastal states to the High Seas met with representatives from the

[2] The full workshop report and associated reports of the 3rd scientific meeting are available on the Internet at: http://www.afsc.noaa.gov/Arctic_fish_stocks_third_meeting/default.htm.

governments of China, the European Union, Iceland, Japan, and Korea in Washington, D.C., USA, to further discuss management of potential fisheries. These participants agreed upon the need for the development of a Joint Program of Research and Monitoring. Additional meetings of these ten governments occurred in April 2016 in Washington, D.C., USA, July 2016 in Iqaluit, Nunavut, Canada, and November-December 2016 in Torshaven, Faroe Islands, Denmark[3].

These discussions led to the development of three Terms of Reference (ToRs) for the 4th scientific meeting:

- ToR 1: **Complete the synthesis of knowledge** – Prior to the meeting there will be a call for existing data and analyses of the High Seas from science organizations of the parties. This will be used to complete the synthesis and integration of analysis of "where we are now", and identify the priorities for research and monitoring gaps. Most of this synthesis should be done prior to the workshop.
- ToR 2: **Develop a Joint Scientific Research and Monitoring Plan to address the four questions** – The primary objective of the meeting shall be to develop a joint Research and Monitoring Plan. This plan shall build upon the outcomes of the three scientific meetings, take the questions from the Joint Program of Scientific Research as the point of departure, and consider the need for additional modeling of ecosystem relationships for areas of the High Seas with physical and biological data relating to commercial fish species. Participants at the meeting shall develop a Science Plan for the next five years showing staged development of research and monitoring that addresses gaps in abundance, distribution and other information required to provide advice about the potential for sustainable harvest of commercial species. The plan shall include:
    - Spatial and temporal scope, objectives and rationale;
    - Use, to the extent possible, existing research and monitoring programs;
    - Incorporation of indigenous and traditional knowledge (ITK), where relevant;
    - Methodology & scientific approach including the need for new research cruises in the High Seas;
    - Appropriate ecosystem (physical, biological, social) indicators;
    - Analysis and modeling strategy; and
    - Data and Information sharing strategies.
- ToR 3: **Provide a Framework for the Implementation Plan** – Participants at the meeting shall use the Research and Monitoring Plan discussion to develop the list of considerations for implementation of the Plan. This Framework shall develop broad options for implementation addressing:

[3] The meeting in Torshaven occurred after the scientific meeting in Tromsø.

- Data needs and how they are to be acquired;
- Additional surveys needed to supplement existing surveys;
- Assessment/synthesis;
- Modeling;
- Hosting of data; and
- Organization of work/Coordination.

The ToRs were designed to build on the results from the first three scientific meetings.

In response to the manager's request, Norway hosted the 4th scientific meeting in Tromsø, Norway, during 26-28 September 2016. In total, 29 participants attended the meeting representing 10 governments (Canada, People's Republic of China, European Union, the Kingdom of Denmark in respect of Greenland, Iceland, Japan, the Republic of Korea, the Kingdom of Norway, Russian Federation, and United States of America) and interested bodies, including the Arctic Council (Protection of the Arctic Marine Environment [PAME]/Conservation of Arctic Flora and Fauna [CAFF]), North Pacific Marine Science Organization (PICES), International Council for the Exploration of the Sea (ICES), and the Pacific Arctic Group (PAG). The participating scientists and others were all familiar with Arctic science, surveys and modeling, and the science necessary to support management and conservation of living marine resources.

The document tabled for ToR1 at the 4th scientific meeting, ***Synthesis of Knowledge on Fisheries Science in the Central Arctic Ocean 2016*** **(SoK, 2016** contained in Appendix B of this report**)**, addresses the information currently available to support the Plan, as do the summaries of available scientific information by Large Marine Ecosystem (LME) submitted by participants in this meeting.

ToR2 for the 4th scientific meeting asked the 10 states to develop a Joint Scientific Research Plan to address the following four main questions:

- What are the distributions and abundances of species with a potential for future commercial harvests in the High Seas?
- What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?
- What are the likely key ecological linkages between potentially harvestable fish stocks of the High Seas and adjacent shelf ecosystems?
- Over the next 10-30 years, what changes in harvestable fish populations, dependent species, and their supporting ecosystems may occur in the central Arctic Ocean and adjacent shelf ecosystems?

Meeting participants were able to refer to two web-based references developed as part of the 3rd scientific meeting: the Inventory of Arctic Research and Monitoring report (IARM) and the breakout group report on the joint monitoring project. The IARM Appendices have links to a wealth of information on the Arctic research and monitoring programs of most of the Arctic nations that were at the meeting.

ToR 3, as addressed at the 4th meeting, began the discussion of an implementation strategy for the Plan, which will be further discussed at the 5th scientific meeting to be held in 2017.

This report documents the results of the 4th scientific meeting. The main body of the report contains two sections, addressing ToR2 and ToR3. The report for ToR1 is included as an appendix to the main workshop report.

II. Joint Scientific Research and Monitoring Plan (ToR 2)

A. Introduction and Background

The ToRs for the fourth meeting of scientific experts on Fish Stocks in the Central Arctic Ocean (FiSCAO) held in Tromsø, Norway, 26-28 September 2016, were the result of discussions among the Arctic coastal states and five other countries and entities in Washington, D.C., in December 2015. The December 2015 meeting reaffirmed that the state of currently available scientific information needs to be improved in order to reduce the substantial uncertainties associated with Arctic fish stocks. ToR2 called for the development of a Joint Scientific Research and Monitoring Plan for the CAO, which we interpret as the High Seas of the Arctic Ocean and surrounding waters.

The governments requested the plan build upon the results from the first three FiSCAO meetings and consider the need for additional ecosystem modelling in the region. The time scale for the Science Plan is 2018 through 2022, and the plan is meant to begin to address gaps in our knowledge regarding abundance, distribution, and processes needed to provide advice on the potential for sustainable harvests of commercial species. This section of the workshop report contains the Joint Scientific Research and Monitoring Plan, a product of discussions among the 10 states during the fourth FiSCAO meeting.

As established at earlier FiSCAO meetings, the geographic focus is on the High Seas and surrounding waters (Fig. 1). The central Arctic LME includes only the deep Arctic basins separated by ridges and sea mounts (Area 13, red boundaries Fig. 1) while the High Seas is the hatched area beyond national Exclusive Economic Zones (EEZs). In addition to the deep basins, the High Seas area includes portions of several continental slope and shelf regions, most notably the Chukchi Borderland. However, to fully understand the fish community components and their variability in the High Seas area, we must also pay some attention to portions of the eight LMEs adjacent to or congruent with the High Seas LME, as well as the four major gateways to the Arctic (i.e., Bering Strait, Fram Strait, the Barents Sea and the Canadian Arctic Archipelago).

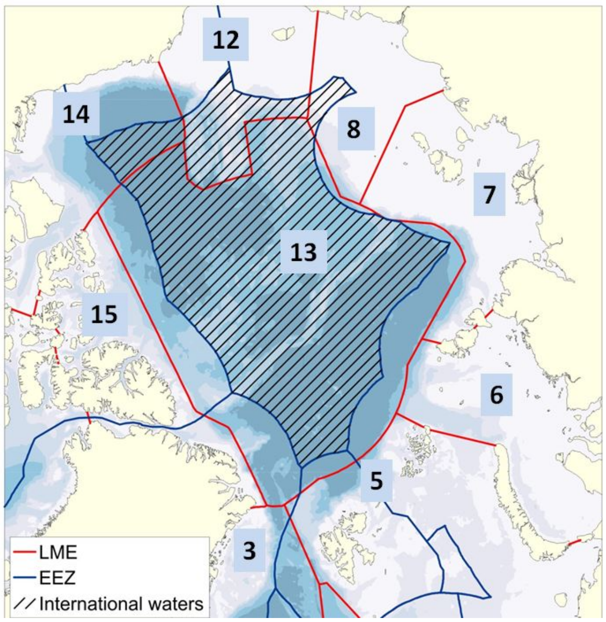


Figure 1. National boundaries (blue) and boundaries of the LMEs (red). The High Seas area (International waters) is hatched. Numbers refer to LMEs defined by red boundaries: 13 Central Arctic LME, 5 Barents Sea LME, 6 Kara Sea LME, 7 Laptev Sea LME, 8 East Siberian Sea LME, 12 Northern Bering-Chukchi Seas LME, 14 Beaufort Sea LME, 15 Canadian High Arctic – North Greenland LME, 3 Greenland Sea LME (northern portion only).

B. Objectives and rationale

The terms of reference identified the following four main questions to be addressed by the Plan (as developed at the 3rd FiSCAO and refined at the December 2015 meeting of governments):

- What are the distributions and abundances of species with a potential for future commercial harvests in the central Arctic Ocean?
- What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?
- What are the likely key ecological linkages between potentially harvestable fish stocks of the High Seas central Arctic Ocean and adjacent shelf ecosystems?
- Over the next 10-30 years, what changes in harvestable fish populations, dependent species, and their supporting ecosystems may occur in the central Arctic Ocean and adjacent shelf ecosystems?

Participants at the fourth FiSCAO meeting reconfirmed the principal aim of the Scientific Research and Monitoring Plan needs to be the collection of information to assess the potential for commercial fishing in the High Seas. Participants at the third FiSACO meeting discussed the concept of ecosystem-based fishery management (EBFM; Link 2010). At the fourth meeting, the participants decided, consistent with ecosystem-based thinking, the focus should not be limited to potential commercial species. Consideration should also be given to environmental drivers of fish and shellfish populations, as well as to those organisms that are closely linked to the target species, prey, predators and competitors, and what effects harvesting commercial species might have on these linked species. This includes non-commercial fish and invertebrate species, as well as organisms at the lower end of the food chain, such as phytoplankton and zooplankton, and at the upper end of the foodweb, such as marine mammals and seabirds (Fig. 2). Such information is essential to answer the latter three questions identified above.

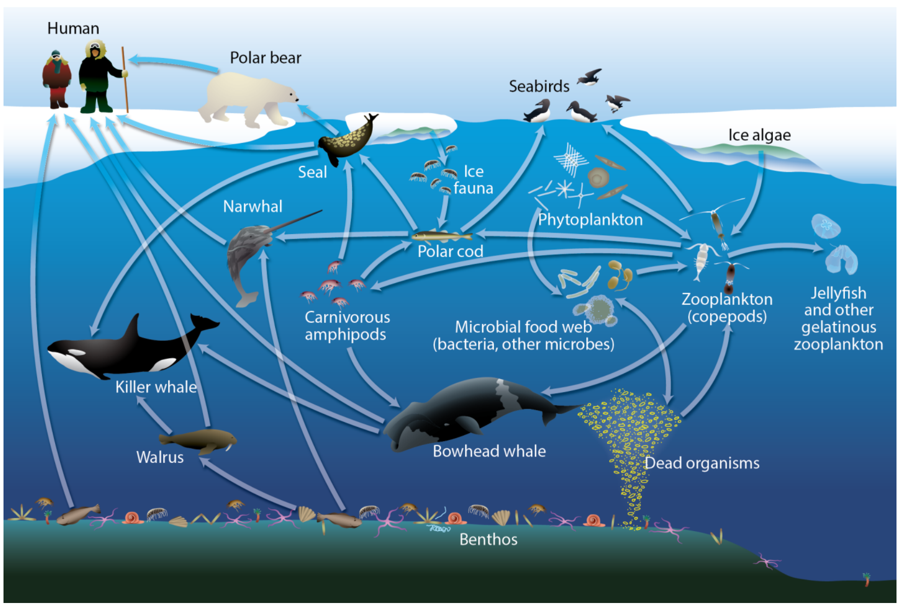


Figure 1. Schematic of an Arctic food web in a shelf ecosystem

During breakout and group discussions, the participants identified more detailed scientific questions that need to be addressed in order to fully answer the four main questions listed above. They are:

- What are the distributions and abundances of species with a potential for future commercial harvests in the central Arctic Ocean?
    - What fish species are currently present in the High Seas?
    - Do fishable concentrations of commercial species exist in the High Seas?
    - What are their distributions and abundance patterns?

    - What are their local life-history strategies, habitat associations, and demographic patterns?
    - Do these strategies, associations or patterns differ among regions in the Arctic?
- What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?
    - What are the trophic linkages among fishes and between fishes and other taxonomic groups (i.e. quantify food web(s))?
    - How do fish species abundances and distributions vary as a function of climate variability?
    - Can the species be harvested sustainably with respect to both target fish stocks and dependent parts of the ecosystem? If not, what are the prospects for the development of fisheries in the future?
- What are the likely key ecological linkages between potentially harvestable fish stocks of the central Arctic Ocean and adjacent shelf ecosystems?
    - What are the connections between fish in the High Seas and those in the adjacent regions?
    - What are the mechanisms that establish and maintain these linkages?
    - How might fisheries in the High Seas affect adjacent and congruent portions of shelf ecosystems, including fish stocks, fishable invertebrates (crabs, shrimp, mollusks), marine mammals, birds and fisheries-dependent communities (which include those communities that are dependent on subsistence harvests of fish, invertebrates, birds and mammals)?
- Over the next 10-30 years, what changes in fish populations, dependent species and the supporting ecosystems may occur in the central Arctic Ocean and adjacent shelf ecosystems?
    - Who are the "winners and losers" in the next 10-30 years?
    - What changes in production and key linkages are expected in the coming 10-30 years?
    - What northward population expansions are expected in the next 10-30 years?
    - What are the anticipated impacts of changes in ocean acidification in the next 10-30 years?

Baseline information, especially on fish populations, is lacking for many parts of the central Arctic Ocean and most notably for the High Seas region, hence a substantial mapping effort is initially required to begin to address the above questions. Here, mapping refers to the initial data collection and analysis in the area with the aim of creating an initial snapshot of the system to assess what species reside in the Arctic High Seas, their spatial variability, and whether abundance levels of potential commercial species could sustain a commercial fishery. Monitoring on the other hand, describes data collection to assess temporal variability in abundance levels and various components of an ecosystem over time, which will be implemented after the initial mapping is completed in the High Seas. Research is needed to assess the data and evaluate mechanisms and changes and is relevant for all four main questions. A description of the mapping and monitoring plans is provided next, followed by additional research activities needed to answer questions 3 and 4.

C. What are the distributions and abundances of species … and what other information is needed…

We anticipate answering the first two questions identified will require the majority of the first five years of the Plan to focus on mapping, modeling and the intitation of a monitoring program suitable for detecting further changes.

1. Mapping of species with potential for future commercial harvest

Very few published accounts of Arctic fishes actually refer to samples from the High Seas. In a search of the literature providing specific locations of capture and similar data submitted by the Parties, the presence of only 12 fish species, and arguably no fishable macroinvertebrates, could be confirmed for the High Seas area (Appendix B). Hence, available data and published descriptions are insufficient to establish the species compositions of the fish and invertebrates, let alone to specify the distributions and abundances of potentially harvestable fish stocks and invertebrates in the High Seas.

A synoptic mapping survey should be carried out, covering as much of the High Seas as possible in order to characterize fish and invertebrate communities and their spatial variability. A one-year survey covering the entire area would be ideal for characterizing spatial variability. If the area cannot be surveyed in a single year, it should be surveyed in as few years as possible (i.e. one to three years in total).

Planning of the sampling strategy should involve survey design specialists, fisheries scientists and oceanographers, as well as data analysts and modelers, to ensure the appropriate and necessary data are collected for the required analyses and are useful for model calibration and validation. The survey should be a synoptic, multi-ship operation with as many nations contributing as possible to obtain the best coverage and collaboration. If the survey is not fully synoptic, then the individual ship surveys should overlap in time as much as possible or be conducted close in time if not overlapping. Standardized data collection program, protocols, and reporting formats are required for all vessels involved in the survey to facilitate combining and comparing the data, especially for abundance estimates. This may require inter-calibration of nets and other instrumentation, as well as revisiting sampling and measurement methods. Where internationally agreed-to best practices are available, these should be used. If none are available, there should be agreement on the data collection methods and data treatment before surveys commence.

Sampling of the biota will focus upon fish and shellfish, especially those species confirmed to occur in the High Seas area that are also considered potential commercial species, e.g. *Boreogadus saida* (called Arctic or Polar cod), *Arctogadus* sp. (*A. borisovi*, known as East Siberian cod; *A. glacialis*, (also called Arctic or Polar cod), *Reinhardtius hippoglossoides* (Greenland halibut). Although not confirmed as occurring in the High Seas, *Chionoecetes opilio* (snow crab) is certainly of interest because it has been sampled from depths nearby in the Beaufort LME and are also found on the High Seas portions of the Northern Bering-Chukchi and East Siberian LMEs. However, in light of the 133 potential commercial species that have been identified in adjacent LMEs (Appendix B), projected northward shifts in fish distributions (Cheung et al., 2010), and the list of species that Hollowed et al. (2013) suggested have high potential to move into the Arctic [e.g. *Hippoglossoides robustus* (Bering flounder), *Pleuronectes quadrituberculatus* (Alaska plaice), *Amblyraja hyperborea* (Arctic skate), and *Sebastes mentella* (beaked redfish)], it is important to adopt an adaptive strategy that can focus on any species with potential for commercial exploitation. Among the invertebrate species, there may be the possibility of harvesting small pelagic crustaceans for their omega-3 (e.g. *Themisto libellulla* in the Arctic).

Surveys of open water areas (vessel-based) should be carried out when the ice-free area is at or close to its maximum. These surveys should (1) use multiple types of fish sampling gear, e.g. longlines, traps, gillnets, etc.; (2) undertake hydroacoustic surveys for pelagic fishes, including ground truthing; and (3) use bottom trawling only in suitable habitats. Environmental DNA (eDNA) sampling may be pursued as a complementary approach to the mapping exercise and may provide a more viable approach given ice conditions and known vessel capabilities.

Should bottom trawling be undertaken, it is advisable to determine if sensitive benthos (e.g. rare species, cold-water corals) are present in the planned trawl area. This should be done using hydroacoustics, side-scan sonar, multi-beam echo-sounders, and/or autonomous vehicles equipped with video recorders. An internationally agreed policy on what constitutes trawlable or non-trawlable bottom conditions will be needed. In near ice-covered areas, surveys should use (1) the appropriate fish sampling gear for the conditions and location, such as longlines, gillnets, traps/pots, etc., (2) Surface Under Ice Trawls, if available, (3) acoustics on gliders or other autonomous vehicles, if available, that can go under the ice, and (4) eDNA sampling.

The species composition, distribution, and abundance (numbers and biomass) estimates of fish and shellfish species will be determined from a combination of catch data and acoustics, depending on species. Acoustic data will provide information on the spatial scale of pelagic fish stocks, with net sampling ensuring correct identification of the species. However, of the expected four main commercial species, only the gadids (e.g., *Boreogadus saida* and *Arctogadus spp*.), which have swim bladders, would be readily detectable by acoustics. Population demographics (maximum and mean length, weight, age, sex, maturity, and fecundity), as well as diet information and trophic linkages for fish species will be determined from stomach contents plus stable isotope and fatty acid analyses. Habitat use will be determined by comparing fish catches with environmental data.

Mapping of ecosystem variables for maintenance of dependent ecosystem components - To understand the dynamics of fish and shellfish species and their role in the ecosystem they inhabit (main question 2), we propose an observation program that also includes several other ecosystem components, including phytoplankton, zooplankton, benthos, marine mammals, and seabirds. As much of these data will be collected on the fish surveys as time will allow. Estimates of plankton and zooplankton biomass and numbers will be made based upon net catches, as well as from acoustic data. Phytoplankton and zooplankton species will be determined from net hauls. During the surveys, on-board observers will identify and count marine mammals and seabirds.

For benthic habitats on the continental shelf and slope areas of the High Seas and for sympagic habitats throughout the High Seas and adjacent waters, initial video surveys using autonomous underwater vehicles will help identify appropriate sampling methods, criteria for stratification, and initial allocations of survey effort. In addition to visual surveys, net sampling of sympagic habitats (David et al., 2015), and a combination of longlines, pots, dredge and nets for benthic habitats, are likely to be appropriate.

The environmental variables to be measured on the surveys should include sea ice, temperature, salinity, currents, dissolved oxygen, pH, pCO_2, alkalinity, turbidity, light levels, nutrients, contaminants and bottom topography and type. Supplementary data on sea ice will be obtained from available satellite imagery (on the web), and some data on bottom topography and type will be available from previous bottom mapping surveys. In addition, environmental data will be collected from long-term (one year or more) moorings, including CTD, nutrient, chlorophyll-a, Acoustic Zooplankton and Fish Profiles (AZFP) data, as well as Acoustic Doppler Current Profiler (ADCP) data. Also, backscatter from ADCP data will provide information on zooplankton and their variability. Acoustic sensors can also be deployed on the moorings, from which information on marine mammal phenology (e.g. time when entering and exiting the Arctic) can be extracted. The moorings should be deployed in strategic areas such as the Arctic gateways, regions of potential fish concentrations, and areas of deep basin-shelf exchange. Deployment of gliders and other autonomous vehicles will be used to collect environmental data under the ice and during periods when the ships are not operating, thus extending seasonal coverage.

Data analysis and evaluation of mapping results - Upon completion of the mapping surveys, the fish data will be merged with any fish data collected by other programs during the same year or time period in order to generate as complete a picture as possible. These should be compared to available historical data to put the survey year or period into a longer-term perspective. A workshop will then be convened to review the data and to determine if there are any fish or invertebrate stocks with sufficient biomass/productivity/surplus production to warrant more detailed surveys to support fishery management advice (i.e. stock assessments.)

A number of quantitative indicators will be developed from the measurements collected during the mapping efforts. For the biota, these will include catch rate and catch per unit effort (CPUE) for the dominant fish species, ratios of demersal to pelagic fish species in terms of both biomass and numbers, of piscivore to planktivores, and of infauna to epifauna, size spectra (slopes of community size spectra), taxonomic diversity, size at maturity, and trophic level or trophic spectrum. From the physical data, indicators will include vertical stratification, mixed-layer depth, light attenuation and nutrient ratios. Further work in this regard should be coordinated with other groups involved in developing indicators such as PICES, the ICES/PAME Working Group on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean, and other ICES working groups.

While new surveys and measurements are paramount to determine what, if any, species have sufficient abundance and productivity to warrant a fishery and to improve our knowledge of ecosystem structure and function in the High Arctic, we must take advantage of existing programs and platforms already operational in the Arctic. This includes having vessels in the Arctic collecting acoustic data capable of fish detection, having marine mammal and seabird observers placed on other Arctic cruises, and being aware of the data collected by the Distributed Biological Observatory (DBO) in the Pacific Sector of the Arctic, the German Hausgarten Observations in Fram Strait, the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC), the Pacific Arctic Climate Ecosystem Observatory (PACEO), Russian on-ice surveys, etc. A list of existing research and monitoring programs presently underway should be developed together with the types of data they collect and where.

If potentially harvestable stocks are identified - If it is determined that there is sufficient fish production to support harvesting of one or more species in the High Seas, then conventional stock assessment monitoring surveys should begin immediately. However, no fishery should commence until it is confirmed through a discussion with the appropriate group of managers that there is the necessary data on abundance and productivity to open a sustainable fishery. The geographic focus of these surveys should be in the area of the target stock and not only the High Seas. An equilibrium condition is a normal assumption of stock assessment methods. However, since it is expected that the High Seas will be a non-equilibrium ecosystem (e.g. due to possible species invasions or climate change), this will require special consideration for the survey and analytical designs. Still, there should be as much consistency as possible between mapping and monitoring phases. Also, as much information as possible should be collected (oceanography, lower tropic levels, higher trophic levels) to be able to undertake an ecosystem level assessment. Potential bycatch would need to be considered within any assessment. Research cruises to determine the life history characteristics of the targeted species, as well as the population and stock dynamics also need to be carried out. Regularly recurring surveys appropriate for generating stock assessment advice to management within an ecosystem context should be undertaken.

If no harvestable stocks are identified - If it is concluded after completion of the mapping surveys that there is not sufficient fish abundance and production in any species to warrant a fishery, then a monitoring plan to detect triggers (indices of change) will be established to determine when to re-sample target areas that may have increased fish stocks relative to the mapping phase. Examples of such triggers include: increased primary productivity in the High Seas based on remote sensing and mooring data; greatly reduced ice cover in the High Seas; northward expansion in distribution of fish stock in an adjacent EEZ with reasonable extension into High Seas (i.e. suitable habitat present); significantly increased primary or fish productivity in an adjacent EEZ; or increased zooplankton biomass in High Seas areas based on moored AZFPs or in EEZs. The moorings established in the mapping phase should be maintained and new moorings deployed if required. Such measurements would have to cover a sufficient area of the High Seas, and nations would need to be identified to carry out such monitoring. Also, there would have to be agreement on the monitored metrics that would trigger a new survey, which should be determined by an international post-mapping phase workshop. Triggers will be regularly monitored for a timely response to changes in conditions within the High Seas or adjacent territorial waters.

Use of Traditional Knowledge - Traditional and local knowledge is a valuable source of information relevant to Arctic fisheries. However, it is anticipated that there would be limited traditional/local knowledge specifically for the High Seas due to the distance between the High Seas and the nearest communities. Coastal communities can still provide valuable data from adjacent regions. In the coastal Arctic, communities are already monitoring the environment and fish populations in some regions, and cooperative monitoring programs to combine these data with scientific survey data could be developed where relevant. In terms of fisheries, local fishers can provide important information, especially in terms of community fish structure and the geographic distributions of fish and marine mammal species, and could collect data on fish demographics, as well as environmental data. Local communities could also be helpful in obtaining diet data and information on trigger variables. Where possible and relevant, nations should begin to contact local inhabitants of the Arctic to determine their interest in participating in such a monitoring program.

2. Monitoring

The extent of the monitoring will, to a large degree, depend upon what is found during the mapping phase. If potential commercial stocks are discovered in the High Seas area, monitoring for stock assessment purposes will be required. If no commercial concentrations of fish or shellfish are found, a minimal monitoring program can be designed with infrequent fish surveys but continued environmental monitoring, especially for the “trigger variables”.

Monitoring of environmental conditions relevant for the ecosystem will include moorings augmented by satellite data on sea ice, near surface temperature, currents through sea level elevation measurements, and chlorophyll-a concentrations when there is no ice. Long-term current moorings in the Arctic gateways are also required to monitor physical, chemical and biological fluxes into and out of the Arctic. Such moorings have been operational in the Bering Strait, Fram Strait and the Barents Sea Opening for one to two decades. These programs should continue and enhance them if considered necessary (e.g. higher spatial resolution, more biological sensors, etc.)

We further recommend that the strategy include a series of accepted fixed stations with standard protocols for biological, biogeochemical and physical sampling, such as the present DBO sites in the Pacific Sector of the Arctic. Ships are encouraged to take measurements at these sites if in the vicinity. Such sites are most convenient in the Arctic gateways as ships can take measurements on their way to and from the Arctic. The present DBO program should be expanded to include more sites, with emphasis on establishing such stations in the Atlantic Sector of the Arctic, particularly in Fram Strait where we can take advantage of long-term national monitoring sites that include the Hausgarten Experiments (Germany) and current meter moorings (Germany and Norway). In addition, measurements for fish and shellfish should be encouraged at DBO sites (Fig. 3). The DBO sites in the Pacific sector of the Arctic are overseen by the PAG, an informal international effort of scientists supported by governments in the form of grants to the PAG secretariat. An Arctic wide coordinating effort similar to that which oversees the DBOs is recommended, or barring that, an Arctic Group formed to oversee DBOs in the Atlantic sector of the Arctic.

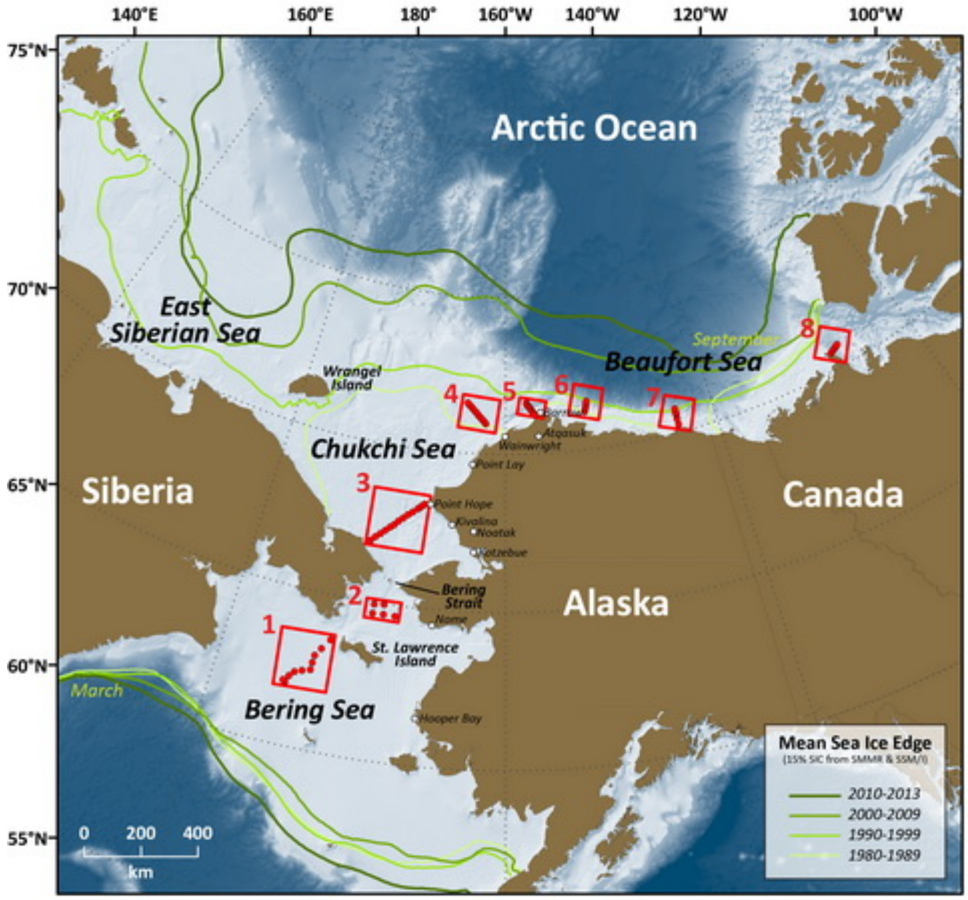


Figure 3. Depiction of the current DBO sites.

3. Modelling

In parallel with the plans for *in situ* and remote monitoring of the Arctic, modelling efforts need to be expanded to help understand and explain observations. Models can also help with the design of observational efforts, such as determining critical locations for particular measurements or sampling frequency. Monitoring plans, on the other hand, should ensure that the results can be used to help calibrate and validate model results. Thus, modellers and observationalists should discuss their necessary requirements to develop a mutually beneficial sampling strategy. This should take place prior to the initiation of the sampling program.

One of the present difficulties related to fisheries is the lack of models that include fish within the High Seas. Exceptions are the environmental envelope models in which future projections of environmental conditons (primarily temperature) are coupled with present observed thermal ranges of different species. The model assumes the species will inhabit a similar thermal range in the future, so projections can be made of the species' future geographical distribution (Cheung et al., 2010). These models are not mechanistic and do not consider potential challenges such as linkages to prey species, potential for recruitment, spawning sites, bottom type for demersal fishes, connectivity between life stages, etc. During the past several years, such mechanistic end-to-end models have been developed for temperate and more southern regions that also include fish and even fisheries. Development and application of such models for the High Seas and adjacent regions are required. This is certainly true if we are to answer the question of how High Seas fisheries would affect adjacent shelf ecosystems, including fish stocks, marine mammals, birds and subsistence-based and fisheries-dependent communities. Improved modelling of predator-prey relationships is needed for which diet data collected during fish surveys should help improve model parameterizations. Zooplankton data collected during surveys and by other instrumentation should provide better estimates of zooplankton abundance and spatial distributions for models.

Some stock assessment models have been developed by the Arctic Fisheries WG of ICES, and the PICES WG28 IFRAME Model has developed ecosystems with reference points. These models, or similar ones, can be used or adapted if sufficient abundances of fish populations are found in the High Arctic. However, no models have been developed for snow crab in the Arctic; modelling will need to be undertaken if there is potential for a fishery on this species.

Models of carbon fluxes and lower trophic levels are presently operational and are being used to examine dynamic processes, variability and influences of climate. These are continuing to be improved. While this strategic plan does not suggest involvement in actual modelling, the program should keep abreast of new developments and the latest results.

D. What are the likely key ecological linkages between potentially harvestable fish stocks of the central Arctic Ocean and adjacent shelf ecosystems?

Key ecological linkages between harvestable fish stocks of the High Seas and adjacent shelf ecosystems can arise owing to: migration for the purposes of feeding or breeding; larval drift; life cycle stages for sessile species; stock expansions that cause a species to move into marginal habitats; a response to strong competition; changing physical conditions; and ecological strategy of species based on their ability to adapt physiologically. In addition, fishing pressure in adjacent areas could impact the abundances of fishes seen in the High Seas. To identify key ecological linkages, an evaluation of the mechanisms at play will be conducted. Those mechanisms can also teach about how fisheries in the High Seas may affect adjacent shelf ecosystems, including fish stocks, marine mammals, birds, and fisheries-dependent communities (which include those communities that are dependent on subsistence harvests of fishes, birds, and mammals). The data will build largely on the mapping and monitoring activity and consider all parts of the ecosystem. The methodology will include the use of, among other things, ecosystem indicators with reference points, Arctic plankton models, ICES Arctic fisheries working group results as well as other fish stock assessment models, carbon flux models, biophysical coupled models (with the need to incorporate sea ice) and the PICES WG 28 IFRAME Model. It will also serve useful to plug in end-to-end models for the High Seas and adjacent areas.

To determine the mechanisms responsible for linkages, we also recommend establishing targeted research projects. It is unlikely there will be sufficient time during fish surveys to carry out all of the necessary sampling (at the appropriate spatial and temporal scales) to address this question. Hence, there is a need for dedicated research cruises. One additional mechanism to explore is the role of eddies that exist along the continental slope and can entrain shelf waters and transport the water and organisms in the water out into the central basins of the Arctic Ocean (Watanabe and Hasumi, 2009; Watanabe, 2011). Dedicated research cruises are also needed to address other distributional issues, such as the location of spawning sites and migration routes of the stocks in question.

Fundamental to fisheries and fisheries management is the question of population structure, for which we have little to no information in the High Seas. To deal with this issue, fish samples from the surveys collected at locations throughout the Arctic should undergo DNA analysis to help determine stock structure. This should be carried out for the major species, especially any potential commercial species. Of particular interest is whether *Arctogadus* in the Arctic is a single species or multiple species. Another example is eelpouts (although unlikely target species for fisheries, they are thought to be ecologically important in some areas), for which there is considerable taxonomic uncertainty in recent research. Taxonomic issues should be addressed using genetic techniques, as well as possibly classical approaches. It is important to know if fish are from different stocks or part of one pan-Arctic stock, as well as connections between fish stocks in the High Seas and adjacent shelf areas. Samples from the latter could be obtained through national surveys, where available.

Habitat utilization of species is a key issue both for understanding linkages and anticipating future changes, and the investigation will start with species that have potential to move from adjacent areas into the High Seas. Identification of species characteristics and habitat characteristics that support movement will be investigated. Target species will be species of potential commercial interest, but other species are also of concern.

E. Over the next 10-30 years, what changes in fish populations, dependent species, and the supporting ecosystems may occur in the central Arctic Ocean and adjacent shelf ecosystems?

Who are the "winners and losers" in the next 10-30 years? - With further reductions in sea-ice cover and associated environmental changes, some species will experience stress, population decline and possibly become extinct while others may take advantage of changes. Reductions in sea ice will directly reduce the habitat available for ice-associated species of fish and marine mammals. Arctic grazers (fishes, seals, walrus, whales and birds) can experience significant changes if their traditional lipid rich prey species are replaced by more boreal, lipid-poor species. Increased migration of foraging boreal/temperate species can have impact on existing arctic resources through increased competition. This issue should be addressed in a broad sense, not only focusing on today's commercial species.

Future decreases in the sympagic food web and increases in open-water plankton biomass can affect species, as well as other components of the ecosystem. Moreover, a shift from an ice-influenced tightly coupled pelagic-benthic system to a less coupled ice-free system can have consequences for demersal fishes and benthos. Other examples of relevance are increased/decreased competition between species, e.g. saffron cod and polar cod in the Chukchi Sea, navaga cod and polar cod in the Kara Sea, and capelin and polar cod in the Amundsen Gulf. There is a clear need for laboratory studies to determine, for example, temperature-dependent growth rates for potential target species. Such information is also critical for bioenergetic modelling efforts. We note that the general physiology of Arctic fish species is, as suggested by Farrell and Steffensen (2005), "woefully under-represented". Indeed, there are only a few laboratories at present that can undertake work on temperature-dependent rates, and we note that they have a hard time obtaining the necessary funding to remain operational. This needs to be addressed. The investigations will include laboratory studies, in situ sampling and modelling studies for predator-prey relationships.

What changes in production and key linkages are expected in the coming 10-30 years? - It is a region's potential with respect to primary and secondary productivity that forms the basis for production at higher trophic levels. Measurements of primary production in the Central Arctic LME show very low levels. With the reduction of sea ice under climate change, there are suggestions that primary production could increase. This issue should be addressed in a broad sense, focusing on both local production in the Central Arctic LME and production on the surrounding shelves, taking into account primary, secondary and fish production, as well as the physical and chemical drivers of the production and advective processes that bring carbon and nutrients from outside.

The Central Arctic LME is characterized by stratified water masses, which causes nutrient limitation on biological production (Tremblay and Gagnon, 2009). With a reduced and thinner sea-ice cover, the productive period will possibly be prolonged and may result in a moderate increase in total yearly primary production (Slagstad et al., 2011). Strong vertical stratification due to seasonal ice melt is likely to limit nutrient supply also in the future. However, increases in upwelling onto the shelves from the deep basins due to the retraction of the ice edge beyond the continental slope may significantly increase production in slope areas (Carmack and McLaughlin, 2011; Tremblay et al., 2011). There are still large unknowns regarding future production in the High Seas. Topics to be adressed include determining the levels of primary and secondary production that exist today and forecasting what levels will be present in the future. These goals should be achieved by combining production calculations using ^{14}C, ^{13}C and changes in nutrient concentration with numerical modelling. It will also be relevant to calculate how much production is needed to sustain fish populations with densities interesting for commercial exploitation with sufficient surplus for marine mammals and birds. Changes in pelagic production (associated with future changes from benthic-dominated systems to pelagic systems) will be evaluated using sea-ice cover as an indicator/trigger for pelagic production (although it still may be nutrient limited). Timing of ice melt/break up could be another trigger/indicator.

Regarding fish production in the High Seas, a major question is whether *Boreogadus* (polar cod) spawning is confined to the shelf areas. Although the High Seas region includes some shelf and shelf break areas, the majority of the area lies over very great depths. Thus, it is an important question whether polar cod is able to spawn with success over deep water with future reductions in sea-ice cover and any associated changes in ocean circulation changes. To evaluate this topic, existing data of genetic stock structure of polar cod should be complemented with new samples to reveal the dispersal and the structure of the stock/stocks. Is there a population in the deep water portions of the High Seas, or is it just spill-over from shallower areas? Current spawning sites must be identified, and whether polar cod will be able to maintain a closed life cycle with future changes in sea-ice cover and ocean circulation/sea-ice drift will be investigated using general circulation models in combination with individual based models of fish and ecological models.

What northward population expansions are expected in the next 10-30 years - Previous studies have projected shifts in bio-climatic habitats of marine fish species and concluded that new species will colonize Arctic ecosystems at an accelerated rate relative to other regions of the globe (Cheung et al., 2010). Closer examination of the processes governing fish distributions revealed range expansions and successful colonization of new regions will depend on a complex suite of factors (Walther, 2010), including habitat suitability, habitat quality and population size (Auster and Link, 2009). A recent assessment of the potential for fish or shellfish stocks or stock groups to move from the sub-Arctic areas into the Arctic Ocean, revealed that several life history factors should be considered when assessing the potential of species to move in response to changing climate conditions (Hollowed et al., 2013).

Investigations are needed to monitor the Pacific and Atlantic gateways to detect migrations and to identify key linkages from the shelves and deeper oceans of the High Seas, including modeling on a species basis. Sampling may be informed by model predictions of likely range extensions species are needed with respect to expected environmental changes to evaluate whether they will become established in the High Seas on a year-round basis or as seasonal migrants. The monitoring and modeling will evaluate what species (e.g. Atlantic herring, blue whiting, mackerel, and capelin) will be seasonal migrants into the Atlantic Artic, and into the Pacific Arctic (e.g. walleye pollock, Pacific cod, sand lance, Pacific salmon). An important issue is also to investigate what determines the boundaries of fish distributions (habitat suitability, etc.).

Another issue of high relevance that should be of focus is the introduction of invasive species with increasing ship traffic, as well as that climate change may open up a route for Pacific species to the Atlantic Ocean and vice versa (Wisz et al., 2015). Bycatches might serves as useful indicators for such species.

What are the anticipated impacts of changes in ocean acidification in the next 10-30 years? - The increase in atmospheric CO_2 and elevated oceanic uptake of atmospheric CO_2 are expected to put stress on marine organisms (i.e., copepods, pteropods and fish), although calcifiers are considered particularly vulnerable. In the Arctic Ocean, enhanced freshening and loss of sea-ice cover will promote further solubility and amplification of ocean acidification. Changes in the Arctic Ocean have already been observed, and the presence of aragonite under-saturated waters on the freshwater-influenced shelves of the western Arctic Ocean in summer 2005 has been reported (Chierici and Fransson, 2009). This change occurred substantially sooner than was predicted by recent dynamic models that suggested it would not happen until 2030 (Orr et al., 2005; Steinacher et al., 2009). Given the potential ecological consequences, studies of processes affecting the natural variability of calcium-carbonate saturation levels in the Arctic Ocean are of great importance in predicting the impact of increased atmospheric CO_2 levels on the vulnerable ecosystems and carbon flows in the Arctic Ocean.

So far investigations are inconclusive as to the extent of the effects of ocean acidification, but it has the possibility to have large impacts in the future, especially given the rapid rate of change in pH in the Arctic. While it is not recommended that a large research effort be initiated within the present program, it is important that the group keep up to date on impacts or potential impacts. Thus, links with AMAP and the work they are doing must be forged. Laboratory studies on the effects of increased ocean acidification on snow crab should be undertaken if this species is found to have potential for commercial fishing and no other group is examining the role of ocean acidification on snow crab shells.

III. A Framework for the Implementation Plan (ToR 3)

Discussions on implementation produced a framework (Fig. 4) with four tracks that would be required to provide the scientific advice necessary to sustainably manage the central Arctic Ocean fish stocks:

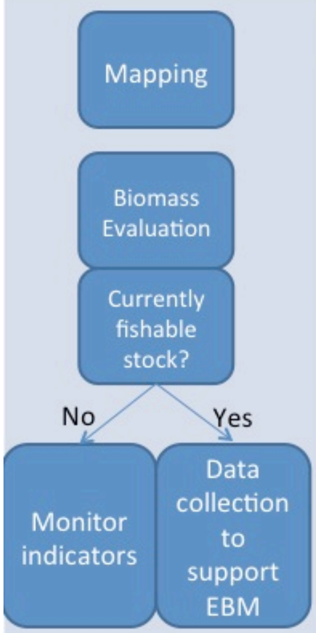
Track A: Mapping and monitoring	Track B: Reference Points and Indicators	Track C: Modeling and scenarios	Track D: Governance
	Occurs in parallel with Track A. • Identify potential biological reference points for managing commercial fish stocks • Assess indicators for potential fish production. • Identify thresholds for primary productivity changes, sea ice change or other triggers.	• Develop approaches to stock assessment and ecosystem modeling. • Agree on possible scenarios (e.g. potentially fishable now; no potentially fishable stocks now, no climate warming; no potentially fishable stocks now but with climate warming.)	Agree on coordinating body to: • Coordinate mapping and monitoring • Monitor indicators • Host biennial meetings and WG to implement Tracks B & C • Set data standards. • Provide Reporting structure.

Figure 4. Schematic of the implementation plan

Such a framework can provide the structure (and ToRs) for discussions at the 5th meeting of Fish Stocks in the central Arctic Ocean later in 2017.

A. Mapping and Monitoring

This track represents the survey elements of the program, and we propose to conduct it in three phases:

- An initial Mapping phase – synoptic initial surveys conducted over two to three years to survey as much of the High Seas CAO as possible and characterize the presence of demersal and shellfish stocks in the region. The product of this work will be the identification of potentially harvestable stocks (if any).

- Monitoring phase - If no harvestable stocks are identified during the mapping phase then work will focus on monitoring for change (e.g., maintained monitoring and sampling stations) by using indices or triggers identified as part of Track B.
- Stock assessment survey phase – If the mapping phase identifies a potentially harvestable stock or the monitoring phase triggers are met, then it will be necessary to conduct focused assessment related surveys for the specific stock/area. This could lead to annual survey appropriate for generating total allowable catch (TAC) advice within an ecosystem context. These surveys should be designed as ecosystem surveys to help further clarify the trophic relationships that can affect the assessment.

Data from the mapping and monitoring phase should be ecosystem focused (e.g., include data on fish stocks, spawning areas, zooplankton, primary productivity, and fish consumers). Circumpolar genetic structure of relevant fish stocks (e.g. polar cod) should be used to define stocks. Data on environmental drivers (e.g. water currents for larval drift, what triggers changes in primary production, upwelling). Results from laboratory experiments with fish (bioenergetics, life history, temperature-related survival and growth rates) will be necesssary. Data on food-web interactions (what the fish feed on, competition, predator-prey relations, etc.) are needed. It is important to have the surveys covering both the shelf seas and the deep ocean (into the High seas) to be able to consider key linkages to shelf seas.

Existing surveys should be continued, but additional surveys will be needed. It is important that all surveys, particularly in the mapping phase, be coordinated to ensure full coverage of the area.

New sampling methods should be considered. For example, use of eDNA may make the mapping phase simpler as it will not require survey vessels to set fishing gear. Under ice sampling methods also need to be further developed using gliders and other autonomous underwater vehicles.

Finally, implementation of the mapping and monitoring phase will require the establishment of some standing group to coordinate the surveys, house the data, etc. (see Coordination section below).

B. Reference Points and Indicators

A separate track will be necessary to identify the reference points that will be used to manage the fishery, and then to determine the appropriate threshold values that would invoke the formation of a Regional Fishery Management Organization and finally a fishery. Appropriate biological reference points should be developed from existing successful fishery management experience and discussed with policy makers to determine which will be used. The menu of potential reference points should be developed at the next scientific meeting on High Seas fisheries and presented to the 10 states at their next meeting for decision. Appropriate threshold values for the reference points should be developed as a Management Strategy Evaluation conducted by a Working Group of scientists from the 10 states.

It will be a major challenge to develop and compute reference points that are robust to the very strong non-equilibrium conditions of the Arctic. The changes in stock's productivity induced by environmental shifts and migrations will need to be taken into account in the definition of the reference points.

Similarly, an evaluation of available ecosystem and fish stock indices should be conducted to provide the monitoring triggers (indices of change) that will determine when to re-sample target areas that may have increased fish stocks relative to the mapping phase. Examples include:

- Increased primary productivity in the High Seas – remote sensing and moorings.
- Reduced ice cover in the High Seas.
- Increased fish stock in an adjacent EEZ.
- Increased productivity in an adjacent EEZ.
- Increased zooplankton biomass in High Seas or EEZ.

While the development of the indices and triggers can be developed using the aforementioned Working Group, there remains a need for a body to monitor the trigger (see Coordination section below). This would include identifying the degree of change in the monitored metric that would trigger a new survey, and that the trigger data are being collected appropriately in time and space.

C. Modeling and Scenarios

Developing an approach to assessment modeling will be necessary to manage High Seas fish stocks. Even if the mapping exercise does not disclose stocks at harvestable levels, it is important to broadly define the approach to stock assessment early on, so as to ensure the appropriate data are being collected. It may be appropriate, given recent advances in modeling data limited stocks and in the use of multispecies modeling to make a decision early on to explicitly incorporate an ecosystem based approach to providing advice. Ecological models (e.g. Gadget, Ecopath, Atlantis), adapted/developed to Arctic Ocean conditions, should be considered to inform the stock assessment modeling.

Given the central Arctic Ocean High Seas will continue to change as ice cover retreats and the ecosystem responds, it is important to directly incorporate this evolving system into the way management advice is provided for High Seas fish stocks. A scenario based approach that explores different alternative futures for the High Seas can provide crucial insights into how stocks should be managed.

Several approaches can be taken for exploring the impacts of these scenarios into assessment advice, and it may be that a suite of different models will be needed to address changes for the next 10-30 years. The models could be simple 1D models to investigate processes. 3D general circulation models with primary and secondary production modules could be used to investigate future changes in primary and secondary production. Fish and possibly also mammals (at least predation from mammals) should also be included. Such models could be forced by IPCC scenarios to evaluate future changes. 3D models with a biogeochemical module could be used to investigate future changes in ocean acidification (in combination with field studies).

These continuing efforts should continue in parallel to the mapping and monitoring effort. Existing studies supported by other Arctic marine science groups may be helpful in this regard.

D. Coordination

It is important that all countries involved in the coordinated research and monitoring program are involved in any coordinating structures pertaining to scientific work. A Coordination Group (CG) for the survey and monitoring efforts, with representation from all involved parties, should be established. This group should facilitate standardization of methods and instrumentation among all survey vessels. Links need to be made with other groups (e.g. Pacific Arctic Group, Arctic Council's CAFF and PAME, ICES, PICES, joint Barents Sea Norwegian-Russian survey, other territorial surveys/monitoring) to avoid duplication of effort and to share data. Also, the CG should organize common data formats, data sharing procedures, data quality assurance/quality control (QA/QC), etc.

As noted above, maintenance of a continuing scientific program for fisheries in the High Seas will require some form of coordination outside of biennial meetings. Key elements that this needs to support include:

- Organize and monitor the mapping and monitoring program
- Support standing WG on reference points/indicators and modeling
- Hosting, maintaining standards, and serving up of data
- Repository for reports
- Providing scientific advice to the multilateral management meetings

Each of these is important to the responsible coordination of the High Seas fishery scientific enterprise.

Nations should work to find agreement on data management policies that would permit sharing of all monitoring and research data. Adhering to open data policies would enable the best and fastest scientific results. Potentially suitable data management policies are already available (e.g., DBO, SAON and IASC, ICES). Such policies could include guarantees for data QA/QC, standard formats and procedures for metadata, and protocols for data exchange (interoperability) that enable data processing independent of software and hardware limitations. Contributing nations would be asked to participate in developing a "distributed" data management system. Distributed systems leave the data and their maintenance to the originator. Distributed systems have search and query capabilities available that can quickly navigate fisheries and ecosystem data in order to aggregate data according to search criteria designed for specific analytic purposes. Copies of the databases would be held by the originator, and potentially by national archives, and third parties such as ICES and AOOS. In the case of third party storage, public data sharing limitations and protocols would be needed. More information on data management is available from the third FiSCAO meeting (Pulsifer, 2015).

There was general agreement that existing scientific bodies working in the subarctic and Arctic could provide the support for this effort, though there was not agreement on which of these bodies (i.e., PICES, ICES, Arctic Council) should be the host. Still, there was no suggestion of the need for a new body to be created.

There was considerable discussion at the workshop about the ICES/PAME Working Group on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean (WGICA), and whether PICES could cohost the WG with ICES and PAME. PICES leadership discussed the topic after the close of the meeting and agreed to join with ICES and PAME to cohost the group.

Further defining the Coordination structure for the scientific enterprise should be one of the Terms of Reference for the 5th Scientific Meeting on Fish Stocks in the Central Arctic Ocean.

Acknowledgements

The Workshop Chairs (Erlend Moksness and Richard Merrick) thank Ken Drinkwater, Kevin Hedges, Randi Ingvaldsen, Phil Mundy and Candace Nachman for their contributions to the preparation of this report and for leading group discussions at the meeting. Jianye Tang provided important edits for the report. Alf Håkon Hoel provided invaluable support for the meeting. We especially thank Candace Nachman for her incredible efforts to edit the report, and Norway's Institute of Marine Research for hosting the meeting.

Appendix A: List of Participants

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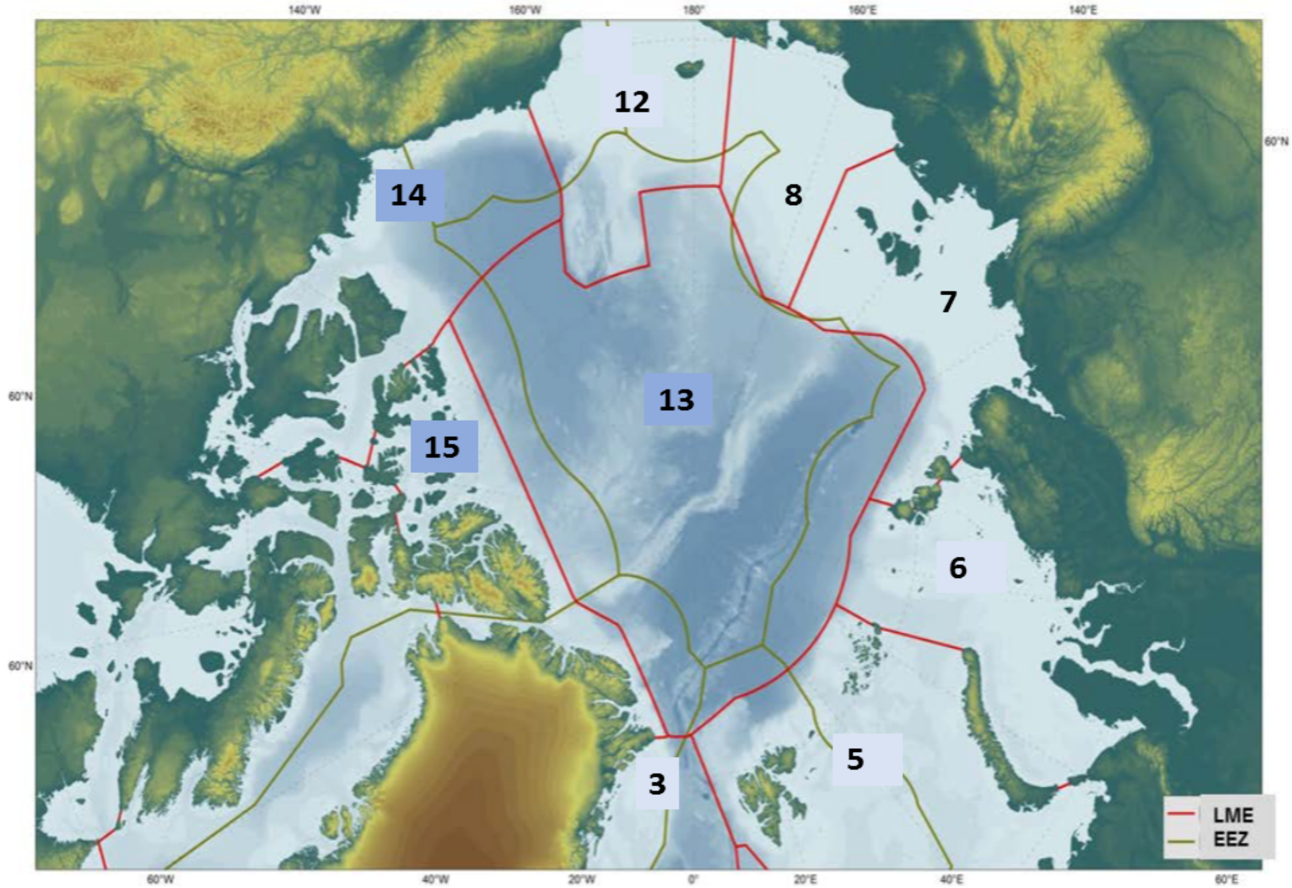
Appendix B: Synthesis of Knowledge on Fisheries Science in the Central Arctic Ocean and Adjacent Waters (ToR1)

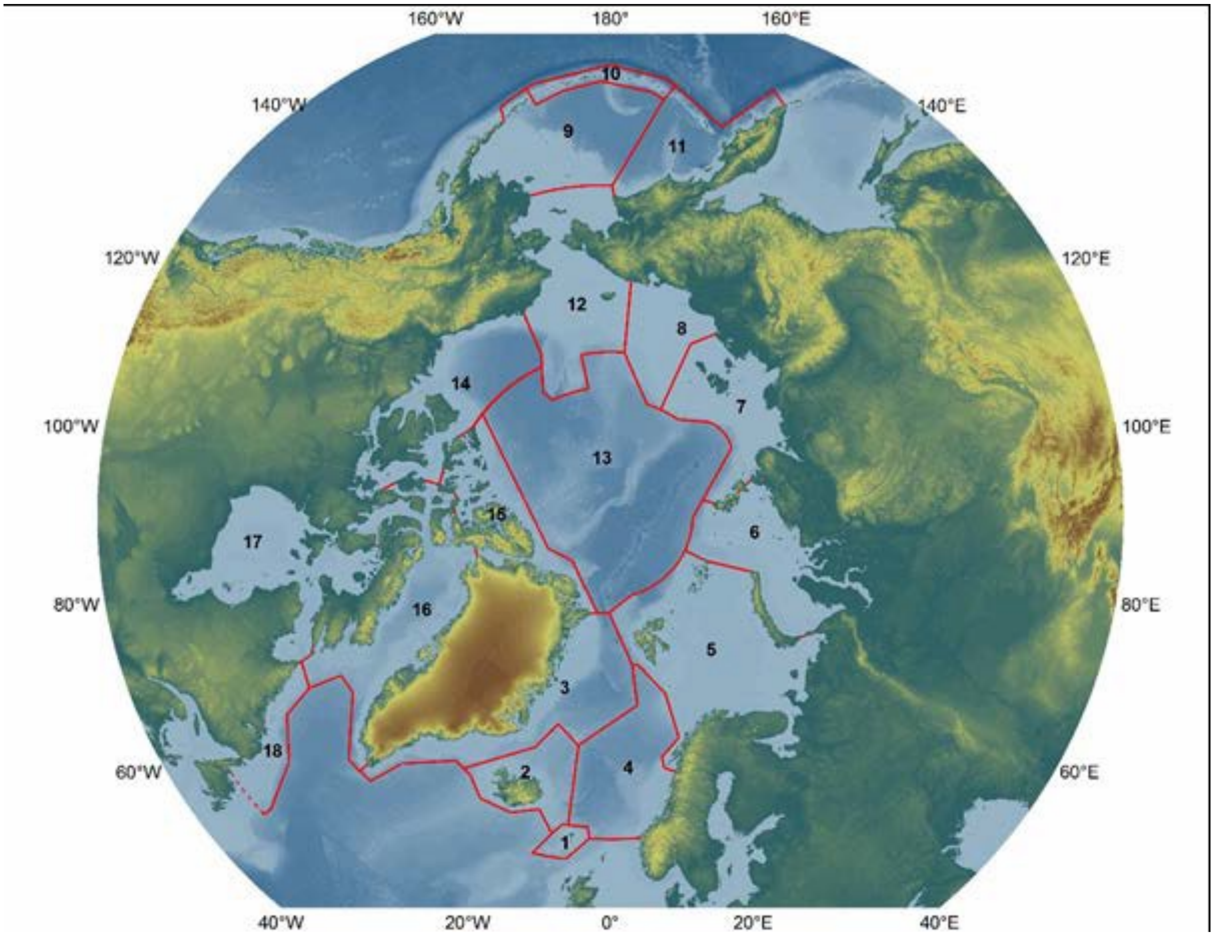
Section Contents

Map of central Arctic showing boundaries of the High Seas (brown) in relation to the boundaries of the congruent and contiguous Large Marine Ecosystems, LMEs (red).



Numbers refer to LMEs defined by red boundaries: 13 Central Arctic LME, 5 Barents Sea LME, 6 Kara Sea LME, 7 Laptev Sea LME, 8 East Siberian Sea LME, 12 Northern Bering-Chukchi Seas LME, 14 Beaufort Sea LME, 15 Canadian High Arctic – North Greenland LME, 3 Greenland Sea LME (northern portion only)

Map of all Arctic Large Marine Ecosystems, LMEs (**URL**) followed by table of areas for the 9 LMEs congruent or contiguous with the High Seas.



Numbers in the table refer to the numbers of the LMEs in the map.

No	Name	Area (millions km^2)
13	Central Arctic LME	3.33
5	Barents Sea LME	2.01
12	Northern Bering-Chukchi Seas LME	1.36
14	Beaufort Sea LME	1.11
6	Kara Sea LME	1.00
7	Laptev Sea LME	0.92
8	East Siberian Sea LME	0.64
15	Canadian High Arctic – North Greenland LME	0.60
3	Greenland Sea LME (northern portion only)	~0.40

Foreword

The current synthesis document is the foundation for the ideal synthesis that will become possible once the Parties develop a data management system that permits assembly of relevant information in formats suitable to synthesis. As such, the synthesis is a portal to relevant knowledge, and it provides a solid foundation of what is known about the distribution and occurrence of fish and invertebrates in the Arctic.

The information on fish and invertebrates provided in the tables of the synthesis is not available elsewhere in the published literature or from any one government agency. The tables are based on records compiled from published and unpublished sources, as provided by the Parties and as acquired from the open literature. The database from which the tables are built is a source of information on the occurrence and distribution of fish and invertebrates in the High Seas of the central Arctic (areas outside the 200 nm zone of the Arctic coastal states; maps at front) and in the Central Arctic Large Marine Ecosystem (LME) and its surrounding LMEs (Maps at front). The database is of course by no means complete; it can be made so only with the further cooperation of the Parties.

The synthesis provides links to over a thousand publications, links to reports on Arctic research programs for the Parties, and its tables are based on an initial database containing over nine thousand records of captures of fish and invertebrates species in the Central Arctic LME and the surrounding LMEs of the Arctic. The records of captures of fish and invertebrate species contain latitude and longitude when available, among other key information, such as the LME and method of capture. Each record has a reference for its origin that can be used to access additional information about the record. Data on species of fish and invertebrates from the surrounding LMEs are considered relevant as information about potential future distribution into the High Seas.

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Executive Summary

What are the distributions and abundances of species with a potential for future commercial harvests in the central Arctic Ocean?

Species with a potential for future commercial harvests in the [High Seas] central Arctic Ocean have been identified in terms of species of occurrence in the High Seas area (Table 1) or surrounding waters (Tables 1.2 and 1.2A) that have a history of commercial exploitation. The presented numbers are based on the current version of the Fish Stocks in the Central Arctic Ocean (FiSCAO) database. The likelihood that any species so identified would eventually have the biomass and growth rate in biomass to sustain commercial harvest is impossible to evaluate with the available data. The presently apparently low primary and secondary productivity on the High Seas are the result of fundamental physical and chemical limitations on annual biological production that indefinitely preclude future prospects for sustainable commercial harvest opportunities.

What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?

To provide advice necessary for sustainable harvest of any fish or invertebrate species, it is necessary to estimate the fishable biomass and the growth rates of the biomasses. To provide advice on maintenance of dependent ecosystems it is necessary to identify and measure the trophic linkages among the commercially targeted species, its prey and its predator species.

What are the likely key ecological linkages between potentially harvestable fish stocks of the central Arctic Ocean and adjacent shelf ecosystems?

The principal key ecological linkages to be monitored are the migrations of potential commercial fish and invertebrate species and their predators and prey from nearby shelf and shelf break areas into the High Seas area, as well as other transports of carbon, such as advection of planktonic species, and addition of atmospheric carbon. As the shallow water areas adjacent to the High Seas warm, the rates of transport of heat and salt (salinity) into the High Seas must be monitored to understand impacts on biological production.

Over the next 10-30 years, what changes in fish populations, dependent species, and the supporting ecosystems may occur in the central Arctic Ocean and the adjacent shelf ecosystems?

Potential commercial fish and invertebrate species and their predators and prey from nearby shelf and shelf break areas can move into adjacent High Seas areas, especially for demersal species into relatively shallow (60 m – 1000 m) High Seas areas, as physical and trophic circumstances permit. Pelagic species are not necessarily limited in their distributions by depth. The rate of movement can only be determined by research and monitoring, as the impacts of climate change on biological systems are not linear, involving many biological feedback loops yet to be identified.

Introduction

Background

Origin and purpose of the synthesis

This synthesis is intended to support discussions that have been ongoing since 2010 on preventing the emergence of unregulated fishing in the High Seas of the Central Arctic Ocean beyond the boundaries of the 200 nm zones of jurisdiction of the adjacent coastal states. The areas of national jurisdiction are often termed Exclusive Economic Zones, EEZ (Maps at front). The ten parties to the discussion as of December 2015 (Canada, Denmark/Greenland, Iceland, Norway, European Union, Russia, United States, China, Korea, Japan), the Parties, called for a synthesis of knowledge (see Terms of Reference 4th FiSCAO in Table of Contents) to serve as the basis for designing a joint scientific research and monitoring program (JSRMP). To consider the synthesis, and other matters, the Parties convened the Fourth Meeting of Scientific Experts on Fish Stocks in the central Arctic Ocean (4th FiSCAO) in September 2016. The discussions of the 4th FiSCAO and the information submitted by the Parties have been integrated with accumulated information from the first three scientific meetings to complete the synthesis presented here. The synthesis provides an entry portal to address the four basic questions posed by the Parties, and it serves as a starting point for the JSRMP under consideration for adoption by the Parties. The priorities for filling research and monitoring gaps may be established by the Parties from the information in the synthesis and the JSRMP.

Geophysical context

Some geographical and biophysical aspects need to be mentioned here, as they provide context essential to understanding the information presented. First, the term, "High Seas of the central Arctic Ocean" also encompasses parts of the Chukchi Sea and the East Siberian Sea, as well as a small portion of the Laptev Sea (see Maps at front). The precision in language describing the High Seas is important because it underlies a critically important geophysical reality; the Pacific Arctic and the Atlantic Arctic are very different in ways that have profound consequences for the distribution and abundance of flora and fauna in the High Seas and surrounding waters. Differences in the fisheries, species and ecosystems of the Atlantic and the Pacific sides will be explored in some detail elsewhere in the synthesis; however, a few essential details are provided here to set the stage.

Between the longitudes of 129° W and 165° E, the "Atlantic" side, the boundaries of the 200 nm zones of Canada, Greenland/Denmark, Norway and Russia lie at latitudes of 80° N or higher, and these zones extend well beyond the continental shelf and shelf break. Consequently, on the Atlantic side, the depths of the High Seas are profound, measuring more than 1000 m near the boundaries. The sill depth between the Central Arctic Ocean and the Greenland Sea is about 2500 m, providing a deep entrance to the Central Arctic Ocean for waters and pelagic species. Between the longitudes of 165° E and 129° W, the "Pacific" side, the boundaries of the 200 nm zones of Canada, the United States and Russia lie at latitudes of less than 80° N to just above 73° N, and they cross over continental shelf and shelf break features. Consequently, on the Pacific side, the depths of some portions of the High Seas are relatively shallow, measuring less than 60 m in some locations near the southern boundaries of the Pacific side of the High Seas.

The present summer ice conditions are also very different on the Atlantic side compared to the Pacific side. Current summer ice reduction on the Atlantic side is much less than on the Pacific side while large reductions are observed in winter sea ice extent, whereas on the Pacific side the summer-fall ice has retreated far towards the north, leaving the Chukchi plateau at times mostly free of ice.

Looking at the biological aspects of these two geographic areas, traditional commercial fisheries in the Barents Sea extend north to almost 81° degrees as of today, whereas commercial fisheries on the Pacific side do not occur above 65° N latitude. Investigations at the shelf slope above 80° N, north of Svalbard and Franz Josef Land reveal commercial fish species to be present in the slope region; however, these areas lie outside the High Seas, being well within the 200 nm zones of Norway and Russia. Investigations on the Pacific side have documented the presence of commercial species on the shelf slope above 72° N, much of which lies within the boundaries of the High Seas.

Information Legacy of the 1st - 3rd FiSCAO

Meetings of scientific experts on fish stocks in the central Arctic Ocean were held in 2011, 2013 and 2015. The successive reports of the meetings reflected a growing awareness of the rapid growth of scientific knowledge in the Arctic, along with the realization of the limited nature of the information on the occurrence, abundance and distribution of fish and invertebrates in the High Seas. The three terms of reference and the four basic questions for the 4th FiSCAO were derived from the report of the 3rd FiSCAO. The report of the 3rd FiSCAO represents a first attempt to set the basic parameters of geographic scope, geographic organization and types of scientific information to be included for the synthesis of knowledge (ToR1 4th FiSCAO). Also addressed in the 3rd report were the JSRMP (ToR2 4th FiSCAO), and the approach to the research framework (ToR3 4th FiSCAO).

Summarizing the main conclusions from the earlier reports show that types of data available from the Central Arctic Ocean are mainly on environment and abiotic factors, and the knowledge of fish and shellfish species is very limited. Substantial information on fish and shellfish from the adjacent LMEs are presented in these three reports, in particular, in the last report from the 3rd FiSCAO. The report is clear on the need for more scientific investigations in the Central Arctic Ocean directly focusing on potential presence of commercial fish and shellfish species. This should lead to a possibility to make an inventory of knowledge relevant to fish and shellfish distribution in the Central Arctic Ocean.

During the time frame of the FiSCAO meetings there is also a substantial amount of reports and publications focusing on climate change and the possible northwards movement of fish and shellfish communities, as the boreal habitats forces the arctic fish and shellfish habitats northwards (Hollowed et al., 2013; Fossheim et al., 2015; McBride et al., 2016). The Arctic fisheries WG of ICES produces a major report which is updated annually, and NOAA produces the Arctic Report card. Also, there are earlier attempts at comprehensive assessments, such as the oceans and fisheries chapters of the Arctic Climate Impact Assessment (2005), and the Fisheries chapter (Christiansen and Reist, 2013).

Synthesis of Knowledge of fish and shellfish

The 3rd FiSCAO (April 2015) produced a wealth of relevant information, including a set of bibliographies and a web-based reference that serves as the entry point to the information supporting this synthesis, the Inventory of Arctic Research and Monitoring report (IARM). The IARM Appendices have links to National Summaries and Review Reports on Arctic Research and Monitoring programs of Canada, China, Greenland/Denmark, Iceland, Japan, Korea, Norway, Russia and the United States. Unfortunately, a complete inventory could not be produced by the 3rd FiSCAO due to data management challenges that are yet to be overcome by the Parties. The conclusions of the 3rd FiSCAO made clear the resources to assemble all the necessary information on fish and their ecosystems in formats that enable analysis are not currently available. Accordingly, the current synthesis document focuses on the immediate need for assembling and analyzing fish and invertebrate data from literature sources, in addition to data submitted by the Parties.

Geographic and Biophysical Scope

How have Arctic ecosystems been defined? The concept of Large Marine Ecosystem was discussed at the 3rd FiSCAO as a starting point in defining the ecosystems that are home to the living marine resources of the Arctic Ocean. The Arctic Large Marine Ecosystems (LMEs) were identified by agencies of the member states of the Arctic Council in 2013 (See Maps at front). The High Seas area is largely congruent with the ecosystem of the Central Arctic LME (See Maps at front) with some important exceptions on the Pacific side. Recognizing that biological and physical linkages between the High Seas, the Central Arctic LME and the ecosystems in adjacent LMEs exist, the starting point for geographic scoping at the 3rd FiSCAO also included the LMEs contiguous with the Central Arctic LME (See Maps at front).

Ecosystem Based Fishery Management (EBFM)

The biophysical aspects of management are further influenced by the information requirements of an ecosystem approach to fisheries management. The 3rd FiSCAO also recognized the principles of EBFM (Link, 2010) as appropriate and important for approaching any regulation of fishing in the High Seas. Both the geographic scope and the types of biological and physical observations (data) relevant to developing information products to support the management of Arctic fishes and invertebrates should reflect the principles and practice of EBFM. In order to implement EBFM on the High Seas and adjacent waters, it is important to routinely gather information on the abundance and occurrence of species of fish and invertebrates, mammals, birds and human populations that depend on the food webs of which the species of fish and invertebrates are integral parts. Such an information gathering effort is here called the Joint Scientific Research and Monitoring Program (JSRMP).

Indigenous and Local Knowledge

Monitoring needs to take into account that future fisheries may affect the indigenous and other local people by altering the ecosystems on which their food security is based. Incorporating indigenous and local knowledge also helps to achieve understanding and cooperation in the implementation of any regulatory measures that may be necessary to limit human activities in order to achieve sustainability.

Species with Potential for Future Commercial Harvests

The presently low intrinsic primary productivity which is symptomatic of the physical and chemical limitations on annual biological production on the High Seas of the Arctic places the prospects for sustainable commercial harvest opportunities in the indefinite future. Nonetheless, the effects of climate have brought about rapid changes in seasonal ice cover on the High Seas over the past two decades, bringing the need to identify and monitor fish and invertebrates species that may have the potential to support commercial harvests on the High Seas in the future. In designating a species as having the potential for future commercial harvest on the High Seas of the Arctic, it is important to have a carefully defined approach and terminology.

The term "commercial fishing" is defined as "fishing in which the fish harvested, either in whole or in part, are intended to enter commerce through sale, barter or trade" (NOAA Fisheries). Fish species documented to occur in the Arctic that have been objects of commerce are considered putative potential future commercial species.

The term, putative, is applied to be clear that the designation of a species as potentially commercial does not mean it is necessarily a commercially viable species. In addition to being demonstrably marketable, a commercially viable species must demonstrate a growth rate in its overall biomass sufficient to provide a sustainable harvestable surplus, and the magnitude of the harvestable surplus must have market value sufficient to justify the allocation of capital to secure its harvest. Knowing biomasses and growth rates of biomasses for putative potential commercial species at any point in the future will require a research and monitoring program.

Records of which species are potential objects of commerce are available. In the United States, the Food and Drug Administration (FDA), in cooperation with the National Marine Fisheries Service, publishes a conveniently searchable database of species that currently are, or have been, commercially marketed in the United States, known as the Seafood List. Pending recommendations for other consistent, objective means of determining commercial potential, the Seafood List is adopted as the source for this information.

The Seafood List was searched for each of the 339 species present in the current version of the FiSCAO database from the High Seas or contiguous LMEs (Table 1). Only species known to occur on the High Seas or contiguous LMEs also listed as commercial species by the United States FDA are designated as potential future commercial species in this synthesis.

Occurrence, distribution, abundance and phenology of selected fish species of the central Arctic Ocean and Adjacent Waters

Introduction

The information presented below is based in part on analysis of 9,405 records of fish and invertebrate species captured in the Arctic LMEs which were assembled from the published literature and from information submitted by scientists of the Parties. Each record contains the following fields: Binomial scientific species name; presence or absence in samples from the High Seas (XCAO); Commercial status according to United States FDA; Latitude; Longitude; Source of data and sampling station; Large Marine Ecosystem; Family; Common name; Depth of sampling location (m); and sampling gear type. Nomenclature for binomials and common names followed the usage of the sources cited, however, when authorities did not agree, the accepted scientific and English common names were taken from the World Register of Marine Species.

Not every field in every record contains information. For example, 8,534 of the 9,405 records have latitude and longitude information. Only records containing latitude and longitude from within the area of the High Seas of the central Arctic Ocean are reported in the lists of species presented in Tables A, 1.1 and 1.1A. The term “fish” refers to both bony fish and cartilaginous fishes (sharks, skates, rays), and the term "invertebrate" refers to species of squid, crab and shrimp. As more relevant publications are identified and new information is published, and as additional information is submitted by the Parties, the understanding of the species present and their geographic distributions on the High Seas and adjacent waters is expected to expand.

Occurrence

There are 12 species of fish in the current version of the FiSCAO database that have been sampled from locations that can be verified to lie in the High Seas area of the central Arctic Ocean (Table 1). No invertebrates of potential commercial usage are currently present in the database from the High Seas area. Of the fish species sampled from the High Seas, three species are potentially of commercial interest, that is, listed in the United States FDA database over species that are or have been commercially marketed in the United States: Arctic cod (*Arctogadus glacialis*), Polar cod (*Boreogadus saida*), and Greenland halibut (*Reinhardtius hippoglossoides*) (Table 1).

There are 339 species of fish and invertebrates in the current version of the FiSCAO database from the LMEs surrounding the High Seas (Tables 1.2, 1.2A and 1.3). The total number of species within the High Seas area is likely to increase as more information becomes available and as taxonomic status of species is further clarified.

Distribution

Overall Distributions

The numbers of species of fish and invertebrates in the current version of the FiSCAO database from each of the LMEs congruent with or contiguous to the High Seas of the central Arctic Ocean species have been identified (Table A). The Barents Sea LME has the highest number of fish and invertebrate species of any Arctic LME, 171 in the current version of the database, and 220 documented elsewhere (Wienerroither et al., 2011; Fossheim et al., 2015). Sixty-four are classified as potential commercial species according to the United States FDA. Second in terms of numbers of species is the Pacific entry portal to the Arctic, the Northern Bering – Chukchi Seas (NBC) LME, with 135 species of fish, including 52 potential commercial species. The Beaufort Sea LME to the east of the NBC LME has almost as many potential commercial fish and invertebrate species as the adjacent NBC, 47, out of a smaller total number of species (113). The Greenland Sea LME covers waters of Atlantic influences in the south and Arctic areas in the north, so the list for this synthesis was limited to 76 northern species identified by Møller et al. (2010) of which 21 were classified as potentially commercial. The East Siberian Sea LME (ESS) has 44 species of which 18 may be of commercial interest. The Central Arctic LME has 34 species with only 6 species of commercial interest. The Canadian High Arctic – North Greenland LME has 30 total fish and invertebrate species, including 6 species of potential commercial use. The smallest number of species reported are reported for the northern Eurasian coast west of the ESS LME where the

Kara Sea LME has 11 total species all potentially commercial, and the adjacent Laptev Sea is reported to have 14 reported species of which 13 may be potentially commercial.

Table A. Summary by LME of total number of fish and invertebrate species in the current version of the FiSCAO database and the number of potential future commercial species in the Arctic LMEs.

Note that many of the species occur in more than one LME. The total number of species in the current version of the database in all nine LMEs is 339 (see Table 1.3) and of those a little more than a third, 133, have a history of commercial use (see Tables 1.2 and 1.2A).

LME	Total Number of Species	Potential Commercial Sp.
Barents Sea, BarS	171[4]	64
Northern Bering – Chukchi Seas, NBC	135	52
Beaufort Sea, BeauS	113	47
Greenland Sea (northern), nGS	76	21
East Siberian Sea, ESS	44	18
Central Arctic, CA	34	6
Canadian High Arctic N Greenland, CHANG	30	6
Laptev Sea, LS	14	13
Kara Sea, KS	11	11

As a general rule, for pelagic and benthic habitats across all LMEs adjacent to the High Seas, most fish and invertebrate species are concentrated on the shelf areas, becoming decreasingly common as depth increases approaching the central Arctic Ocean. However, exceptions are found in the Greenland Sea and Fram Strait, for example, in pelagic habitats related to deep sea layers that support a variety of species.

The waters near the boundary of the High Seas on the Atlantic side are quite a bit deeper than those of the boundary areas on the Pacific side. Depths of waters of the High Seas areas on the Pacific side have a minimum depth of about 60 m, whereas the minimum depth on the Atlantic boundary exceeds 1000 m. The sill depth in Fram Strait is about 2500 m, thus providing a possible deep gateway to the Central Arctic Ocean for pelagic species in the Greenland Sea. Unlike the Atlantic side, the Pacific side has extended shelf areas adjacent to the High Seas boundary with waters less than 60 m in the LMEs on the Pacific side (NBC, ESS, Laptev Sea). Most of the areas less than 1000 m

[4] 220 documented by Wienerroither et al. (2011) and Fossheim et al. (2015)

in the High Seas are adjacent to NBC and ESS and to a lesser extent the Laptev Sea, LS. Hence, the Pacific Arctic has a substantial number of potential commercial demersal fish and invertebrate species in proximity to waters of the High Seas that are shallow enough to provide habitat for future expansion of these commercial species, all other determining factors of distribution aside. The combination of bathymetry and biology favorable to future expansion of commercial fish and invertebrate species into the High Seas is located toward the western American and eastern Eurasian continental areas.

Depth is also closely related to seasonal ice cover on the Pacific side, with the shallower areas more often being ice free for part of the year. As a consequence, knowledge about fish and invertebrates in pelagic and benthic habitats of deeper waters is limited. Larger benthic fish and the sharks and rays appear to be distributed roughly inversely proportional to depth, but the lack of effective sampling methods (i.e. longline and pot gear) that is icebreaker deployable constitutes a substantial gap in essential information.

Fish distribution on the Atlantic side of the Arctic is known from the joint Russian-Norwegian ecosystem surveys from 2003 until present and also from the exploratory Norwegian surveys in an ongoing strategic initiative to explore the Arctic, undertaken by the Institute of Marine Research in Norway. These observations are in addition to a long historic record established through research surveys conducted by scientists from Norway and Russia since the 1960s. As a consequence, the biota and ecosystems in the Barents are the best known of the nine Arctic LMEs in this synthesis due to the presence of the long time series of information generated by the annual scientific surveys.

Some fish species are found only in the northern areas of the Barents Sea shelf, and some other species are found to have an expanding northerly distribution. Recent observations of Greenland shark (*Somniosus microcephalus*) indicate this species to be an important top predator in the Arctic waters. Several skates (*Amblyraja hyperborea*, *A. radiate, Rajella fyllae*) are also found in northern waters. Several species of small mesopelagic fishes (*Benthosema glaciale, Lampanyctus macdonaldi* and *Notosepelus kroyeri*) are found close to the bottom in the northern slope of the Svalbard shelf. Several species of grenadiers (e.g. *Macrorurus berglax)* are found at the northern slope, as are rocklings (e.g. *Gaidropsarus argentatus*), and sculpins (*Gymnocanthus tricuspis, Icelus* spp., *Triglops nybelini*), poachers (*Leptagonus* spp.), lumpfishes (*Eumicrotremus spinosus*) and a number of snailfish species (e.g. *Liparis fabricii, Paraliparis bathybius, Rhodctys regina*), and finally a large number of eelpout species (*Lycodes* spp.) and blennies (*Lumpenus* spp.).

As mentioned earlier, a number of commercial species in the Barents Sea are seen to expand their distribution northward, and some of these species may be candidates for expanding their distribution into the Central Arctic LME and possibly farther north into the High Seas. Greenland halibut is clearly seen to expand its juvenile distribution to the northern side of the Svalbard shelf, and it is observed in the pelagic at considerable depths north of Svalbard. Also, pelagic fish species are observed far to the north, and, in particular, the distribution of mackerel, herring and blue whiting extend surprisingly far north in the later years. Semi-pelagic fishes such as beaked redfish (*Sebastes mentella*) are observed with distribution north of Svalbard, and this species may be related to deep sea biotic layers and may extend its distribution further north. Cod and haddock are also seen far north, and cod is observed well above the bottom in deep waters north of Svalbard. Both polar cod and Arctic cod are observed far north, however without any clear signal of changing distribution. In addition to fish species, the northern shrimp (*Pandalus borealis*) is found on the northern side of the Svalbard shelf, at considerable depths.

On both the Pacific and Atlantic sides of the Arctic LMEs (Table 1) the lack of observations on distribution of fish and invertebrates in ice-covered benthic habitats is added to the lack of systematic scientific observations on the distribution of fish in under-ice pelagic habitats. Anecdotal accounts from nuclear submariners from the 1950s and 1960s describe schools of fish of unknown species that extend for kilometers in the pelagic areas under the ice of the High Seas within 300 nm of the North Pole. Methods of sampling fish under the ice in sympagic, pelagic and benthic habitats are essential to successful research and monitoring efforts in the High Seas and adjacent waters.

Distribution of Polar cod (*Boreogadus saida*)

Boreogadus saida have an Arctic circumpolar distribution, occurring in the North Pacific, Arctic and North Atlantic Oceans (Catherine W. Mecklenburg, Møller, & Steinke, 2011). The southern range of their distribution extends just south of Bristol Bay in the Bering Sea (Allen & Smith, 1988) and on the Atlantic side in the Gulf of St. Lawrence, Hudson Bay, Iceland and south of Greenland (Catherine W. Mecklenburg et al., 2011). To the north, they occur in the central Arctic Ocean (David et al., 2016; I. A. Melnikov & Chernova, 2013). *Boreogadus saida* have been observed in brackish lagoons, river mouths and in the ocean to depths of 731 m. They are often associated with ice and have been observed in wedges of water within ice floes (David et al., 2016; R. R. Gradinger & Bluhm, 2004). Large schools of adults have been observed in shallow water in the late summer (Crawford & Jorgenson, 1996). Often, *Boreogadus saida* are found segregated by age over continental slope regions with adults at depths of 150-400 m and younger fish in shallower depths (Benoit, Simard, & Fortier, 2008; Geoffroy, Robert, Darnis, & Fortier, 2011; Parker-Stetter, Horne, & Weingartner, 2011).

Distribution of Arctic cod (Arctogadus glacialis)

Arctogadus glacialis also have an Arctic circumpolar distribution, but their range is smaller than *Boreogadus saida*. *Arctogadus glacialis* have been observed in the Beaufort Sea northeast of Barrow (Frost & Lowry, 1983) throughout the Arctic to western and eastern Greenland, Barents Sea to East Siberian Sea and in the central Arctic Ocean as far north as near 81°24′ N, 178°16′ E (Andriyashev, Mukhomediayarov, & Pavshtiks, 1980) and 81°41' N, 29°01′ E (Aschan et al., 2009). Unlike *Boreogadus saida*, *Arctogadus glacialis* do not extend down into the eastern Chukchi Sea, though they have been occasionally observed in the western Chukchi Sea (Catherine W Mecklenburg, Mecklenburg, & Thorsteinson, 2002). They have been caught at depths from the near surface down to 930 m (Jordan, Møller, & Nielsen, 2003). In the European Arctic, they are most commonly found at depths of 300-400 m (Aschan et al., 2009).

Distribution of Greenland halibut (*Reinhardtius hippoglossoides*)

Greenland halibut have a circumpolar distribution, occurring in both Arctic and boreal waters. They have been found in the high Arctic, as far north as 75° N on the Chukchi slope and 77° N off Greenland (Catherine W. Mecklenburg et al., 2011). They inhabit depths from 20–2000 m with a preferred depth range of 400-1000 m (Bowering & Nedreaas, 2000). In the northeast Atlantic in Arctic latitudes, spawning grounds are along the continental slope near Svalbard and northern Norway (McBride et al., 2016).

Distribution of Arctic skate (*Amblyraja hyperborea*)

Arctic skates have an Arctic (and possibly Antarctic) circumpolar distribution (Catherine W. Mecklenburg et al., 2011). Their depth range is 140–2500 m, usually 300–1500 m and are found in temperatures < 4°C (Dolgov, Drevetnyak, & Gusev, 2005; Peklova, Hussey, Hedges, Treble, & Fisk, 2014). Specimens were observed by remotely operated vehicles at 74°20′ N at 1,800 m depth in the Canada Basin (Stein, Felley, & Vecchione, 2005). Although samples of Arctic skate with known latitude and longitude are not available, Arctic skate are almost certainly present in the High Seas area, and the skates are potential future commercial species, having documented histories of commercial use.

Abundance

Abundance of Polar cod (*Boreogadus saida*)

The stock biomass of Barents Sea *Boreogadus saida* has been estimated through annual acoustic surveys since 1986. Biomass estimates have ranged between 0.1-1.9 million metric tons (mt) with most recent estimates in 2012, 2013 and 2014 declining from roughly 0.5 million mt to 0.34 million mt to 0.24 million mt (ICES, 2015). In the 1950s, a *Boreogadus saida* fishery developed in the Barents Sea (Andrii□a□shev, 1964). Concentrations of *Boreogadus saida* are fished in late autumn during southward spawning migrations along the coast with pelagic trawls. However, there has been no fishery since 2012 due to low interest (McBride et al., 2016). In 2011, Russia harvested 19,600 mt in the Barents Sea in ICES statistical area I (ICES, 2012, p. 31).

In the U.S. Chukchi Sea, *Boreogadus saida* area-weighted biomass and abundance estimates were 31,500 mt and 2.6 billion individuals based on a 2012 bottom trawl survey (Goddard, Lauth, & Armistead, 2014; North Pacific Fishery Management Council (NPFMC), 2009). Recent biomass estimates were slightly higher than the 27,000 mt estimate based on 1990 bottom trawl survey data (Barber, Smith, Vallarino, & Meyer, 1997; North Pacific Fishery Management Council (NPFMC), 2009). However, the survey area used in the biomass estimate was roughly half the survey area of 2012. Also, 2012 and 2013 summer acoustic survey estimates of age-0 *Boreogadus saida* in the U.S. Chukchi Sea were 80 billion and 240 billion individuals, respectively (De Robertis, Taylor, Wilson, & Farley, 2016). There is a possible mismatch between the high abundances of age-0s and apparently relatively low adult abundance. On the Russian side of the Chukchi Sea, biomass estimates of *Boreogadus saida* have ranged from 674,200 mt in 2003 to a low of 12,600 mt in 2008, and most recently, 45,700 mt in 2010 (Datsky, 2015).

Boreogadus saida is the most abundant fish species in the Beaufort Sea LME (Benoit et al., 2008; Geoffroy et al., 2011; Lowry & Frost, 1981; Parker-Stetter et al., 2011; Rand & Logerwell, 2011). Different age groups of *Boreogadus saida* have been observed to segregate by depth (Geoffroy et al., 2015; Parker-Stetter et al., 2011). In the United States Beaufort age-1+ *Boreogadus saida* dominated the pelagic biomass with acoustic survey estimated peak densities of 155,000 fish/ha, near the bottom at depths from 100-350 m, while age-0 *Boreogadus saida* had peak densities of 160,000 fish/ha at bottom depths of 20-75 m and usually formed schools between 20-40 m (Parker-Stetter et al., 2011). In the United States Beaufort, the *Boreogadus saida* biomass was estimated to be 15,000 mt based on a 2008 bottom trawl survey (North Pacific Fishery Management Council (NPFMC), 2009; Rand & Logerwell, 2011).

In the Lancaster Sound region (97,698 km^2) of the Canadian High Arctic LME, acoustic survey associated mean density estimates of *Boreogadus saida* were 22 fish/ha, 6000 mt extrapolated to the entire region, which is too low to support the marine mammal and seabird populations (Welch et al., 1992). The low estimates were attributed to an absence of schools observed in the survey (Welch et al., 1992). Large aggregations of adult *Boreogadus saida*, with up to 670 million individuals (density 307 fish/m^3) weighing >23,000 mt have been observed in a shallow bay (10 -25 m) in the Canadian High Arctic (Crawford & Jorgenson, 1996).

Boreogadus saida have been observed under the ice in the Central Arctic LME. During August and September 2012, the median abundance was estimated as 50 individuals/ha in the surface layer (0-2 m) directly under the ice of primarily age-1 *Boreogadus saida* (David et al., 2016). Both the sea-ice formed and *Boreogadus saida* originated from the Laptev Sea LME and the Kara Sea LME, and these areas likely serve as important recruitment grounds for the observed cod (David et al., 2016). In the winter (starting in October with largest events in November and December), large (qualitatively described as dense schools being observed at the hydro-hole for 1-3 days at a time) swarms of

Boreogadus saida have been observed under Russian drifting stations North Pole-16 (NP-16) in 1968-1969 (Andriyashev et al., 1980) and under NP-37 in 2009-2010 (I. A. Melnikov & Chernova, 2013).

Abundance of Arctic cod (*Arctogadus glacialis*)

Arctogadus glacialis are more common in the Atlantic Arctic than in the Pacific Arctic. Lowry and Frost (1981) caught one *Arctogadus glacialis* at a depth of 150 m during their 1977 survey of the U.S. Beaufort Sea. No *Arctogadus glacialis* were caught in a 2008 survey of Beaufort Sea (Rand & Logerwell, 2011). *Arctogadus glacialis* were the most common fish sampled under the NP-16 drifting station in 1968-1969 in the central Arctic (Andriyashev et al., 1980), but none were sampled under the NP-37 drifting station in 2009-2010 (I. A. Melnikov & Chernova, 2013). Also, *Arctogadus glacialis* were the dominant fish caught (796 total) during a bottom trawl survey (depths 110-490 m) on the shelf to the northeast of Greenland (Sufke, Piepenburg, & von Dorrien, 1998), and *Arctogadus glacialis* are often observed in fjords on the northeastern side of Greenland (Christiansen, Hop, Nilssen, & Joensen, 2012). Overall, it appears that *Arctogadus glacialis* are much less abundant than *Boreogadus saida* in Arctic waters.

Abundance of Greenland halibut (*Reinhardtius hippoglossoides*)

Greenland halibut are much more abundant in Arctic latitudes of the Atlantic Ocean compared to the Pacific Ocean. In the U.S. Chukchi Sea, a mean CPUE of 0.01 fish/ha was observed during the 2012 bottom trawl survey (Goddard et al., 2014). In the U.S. Beaufort Sea, a mean CPUE of four fish/ha and 0.4 kg/ha was observed during a 2008 bottom trawl survey (Rand & Logerwell, 2011). The low numbers and absence in ichthyoplankton surveys indicates that the observed Greenland halibut likely spawn in the Bering Sea and are transported north to the Chukchi and Beaufort Seas (Logerwell et al., 2015).

In the Atlantic Ocean, Greenland halibut spawn in Arctic latitudes. Fisheries occur in the Barents Sea and in the Canadian Eastern Arctic-West Greenland LME. In the Barents, over the last 10 years, average annual catch has been around 17,000 mt (McBride et al., 2016). The majority of the catch is split between Norwegian and Russian gillnet, longline and trawl fleets (ICES 2015). Currently, there is no accepted assessment, and biomass estimates are based on fishery data and independent surveys (ICES, 2015). The 2014 exploitable biomass estimate for Greenland halibut (> 45 cm in length) is approximately 650,000 mt with an abundance of 380 million individuals (ICES, 2015, page 558). In the Canadian Eastern Arctic-West Greenland LME (NAFO Subareas 0 and 1) the 2015 biomass estimate for Greenland halibut is roughly 190,000 mt (NAFO, 2016).

Abundance of Arctic skate (*Amblyraja hyperborea*)

Arctic skates are common bycatch in Atlantic Arctic bottom trawl and longline fisheries. In the Barents Sea, their bycatch rates are up to 60–100 kg per hour haul and >50 fish per 1,000 hooks (Dolgov, Grekov, Shestopal, & Sokolov, 2005). Stock abundance and biomass estimates from the autumn/winter trawl survey in the Barents Sea are 2.6 million skates and a biomass of 3,500 mt, respectively (Dolgov, Drevetnyak, et al., 2005). The survey catch of Arctic skates increased with depth, and the maximum depth of the survey is 800 m, which does not include the full preferred depth range (Dolgov, Drevetnyak, et al., 2005).

Phenology

Phenology of Polar cod (*Boreogadus saida*)

Little is known about the geographic phenology of Polar cod, especially during the winter months. Polar cod reach a maximum length of 40 cm (Craig, Griffiths, Haldorson, & McElderry, 1982), but usually are less than 30 cm (Bradstreet, 1986). The maximum recorded age is eight years (Gillispie et al., 1997). Because Polar cod spawn in the winter under the ice, little is known about spawning locations and whether they spawn nearshore and/or in deeper waters. Two potential locations have been identified in the Barents Sea: east of Svalbard (inferred from egg and larval drift (Hop and Gjosaester, 2013) and Pechora Sea (Rass, 1968). Typically, males reach maturity earlier than females (Andriyashev, 1954; Craig et al., 1982; (Nahrgang et al., 2014);(Nahrgang et al., 2016). On average, females reach maturity at three (Barents Sea and Alaskan Arctic) to four (Russia) years of age (Andriyashev, 1954). Age of first maturity can occur as early as one year of age for males and two years of age for females in the coastal waters of the Beaufort Sea (Craig et al., 1982). Time of spawning ranges from December to March with peak spawn timing occurring in January and February in the Barents Sea and the U.S. Arctic (Rass, 1968; Craig et al., 1982; Lowry and Frost, 1981; Korshunova, 2012). Polar cod are believed to be complete broadcast spawners (Korshunova, 2012), investing high levels of energy in reproduction and can lose up to 50% of their body weight while spawning (H. Hop, Graham, & Trudeau, 1995). Most of the egg development takes place in the ice-water interface (Rass, 1968). Embryonic development of Arctic cod ranges from 26 to 90 days with shorter times occurring in warmer temperatures (Aronovich, Doroshev, Spectorova, and Makhotin (1975); Rass, 1968; Graham and Hop, 1995; (Ponomarenko, 2000). Hatching season starts in January in areas with freshwater input and favorable temperature conditions (Laptev, Siberian and Beaufort seas and Hudson Bay) and in April in areas with little freshwater input (Canadian Archipelago, North Baffin Bay and Northeast Water) and ends in July (Bouchard & Fortier, 2011). In the Canadian Beaufort Sea, Geoffrey et al. (2015) observed a year round vertical segregation of age-0 in waters < 100 m and age 1+ at depths of 200 – 600 m. Starting in September, the age-0s start to transition down to the mesopelagic. Starting in late January and peaking in April, Benoit et al. (2008) observed large aggregations of adult, possibly spent and fasting, Polar cod in ice-covered Franklin Bay in the Canadian Beaufort in the lower part of the Pacific Halocline. Benoit et al. (2008) hypothesized that cod may have passively drifted from the Amundsen Gulf and were seeking refuge at depth from diving ringed seals or metabolically advantageous water temperature.

Phenology of Arctic cod (*Arctogadus glacialis*)

Very little is known about the life history and phenology of Arctic cod. The maximum age is at least 11 years (Boulva, 1979), and maximum length is 60 cm (Mecklenburg et al., 2002), so they are longer-lived and grow larger than polar cod. Early life stages of Polar and Arctic cods are morphometrically similar (Bouchard et al., 2014). Within the literature, there are contradictory statements about spawn timing. Sufke et al. (1998) and Bouchard et al. (2014) suggest winter spawning, while other evidence suggests summer spawning (Jordan et al., 2003; Aschan et al., 2009). In the Canadian Beaufort, Polar and Arctic cods have a similar hatching season, spatiotemporal distribution and growth rates, but higher survival (Bouchard et al., 2014), which supports winter spawning. Jordan et al. (2003) speculates that Arctic cod spawn inshore, and the juvenile development may take place offshore where large numbers of medium-sized fish have been observed (e.g., Northeast Water off Greenland in von Dorrien et al., 1991).

Research gaps in phenology

Few studies have surveyed Arctic and polar cod under the ice in winter, therefore, little is known about their spawning ecology, shoaling behavior, seasonal movements, abundance and distribution. Even less is known about Arctic and Polar cods inhabiting the central Arctic, which is currently ice covered year round. For a fishery stock assessment, we need a good estimate of total biomass, natural mortality, predation mortality, age of maturity, fecundity, a detailed age structure, etc. There is a need for large systematic annual or biennial surveys (e.g., annual acoustic surveys of Arctic cod in Barents Sea since 1981 (ICES, 2012).

Marine Food Webs of the Central Arctic Ocean and Adjacent Waters

Biota

Sympagic

Communities of plants animals and other organisms depend on sea ice as habitat, feeding ground, refuge, and breeding ground. The specialized ice inhabitants are known as sympagic (or ice associated). Sympagic diversity contributes considerably to total Arctic diversity. Sympagic biota range from microbes to megafauna (H Hop, Bluhm, Daase, Gradinger, & Poulin, 2013). Primary producers, such as diatoms, are considered the most significant sympagic species. Other species to inhabit the Arctic sea ice include nematodes, cnidarians, copepods, rotifers, polychaetes, euphausiids, and amphipods. Amphipods produce a major food source for *Arctogadus glacialis,* who also occur within sea ice and act as a major link between the ice-related food web and seals and whales (R. Gradinger et al., 2010). *Boreogadus saida* are known to occur in narrow wedges of seawater along the edges of melting ice sheets in schools of 1-28 per wedge where amphipods are also known to occur (R. R. Gradinger & Bluhm, 2004).

Sea ice habitats appear to be undergoing change regarding suitability and availability for the associated biota during their entire life cycles. This change is indicated by regional declines in their abundance and biomass. As multiyear ice habitat declines, pressure ridges in first-year ice may become more important as refuge for sympagic species (H Hop et al., 2013).

Pelagic

Pelagic communities in the Arctic are coupled to the seasonal cycles of the pelagic primary production and the seasonal downward flux of ice-algae during breakup (R. Gradinger et al., 2010). Pelagic biota consists of mainly phytoplankton, bacteria, heterotrophic protists, copepods, euphausiids, mysids, larvaceans, chaetognaths, and cnidarians (R. Gradinger et al., 2010). Arctic fishes such as Pacific cod (*Gadus macrocephalus*) and the black snailfish (*Paraliparis bathybius*) are present in the western Arctic. Other fish species present, for example, are walleye pollock, veteran poachers, Arctic cod, Polar cod, whitefish, saffron cod, capelin, Greenland halibut, Atlantic herring, and others (Bluhm & Gradinger, 2008; R. Gradinger et al., 2010).

Benthic

Recent measurements of benthic biological production in the Arctic have shown that the central Arctic Ocean is not as barren as originally thought (Vanreusel et al., 2000). Nematodes have been shown to occur as the numerically dominant species in numerous sampled stations (Vanreusel et al., 2000). Other small-sized sediment-inhabiting organisms of the central Arctic Ocean include bacteria, flagellates, protozoans, and foraminiferans (Schewe, 2001). Several fish species also inhabit the benthic areas of the central Arctic Ocean. Among these demersal fish species are Arctic cod, Polar cod, eelpouts, Greenland halibut, sculpin species, and walleye pollock (Lin et al., 2012; Catherine W Mecklenburg & Steinke, 2015; I. Melnikov, 1997).

Environmental Drivers of Fish Production

Oceanography

The Pacific Arctic marine ecosystem consists of inflow shelves from the northern Bering and Chukchi seas, along with the interior shelves of the East Siberian and Beaufort seas (Moore & Stabeno, 2015). Each of these domains possesses different biophysics characteristics (Carmack & Wassmann, 2006). The flow through the Bering Strait links the Pacific and Arctic oceans and impacts the oceanic conditions in the Chukchi Sea and Western Arctic (Kinney et al., 2014). One impact includes large amounts of heat and freshwater being delivered annually into the Chukchi Sea from the Bering Strait (Kinney et al., 2014). The interior shelves are influenced by the outflow of warmer fresh water from Arctic rivers (Carmack & Wassmann, 2006).

In the Atlantic Arctic marine ecosystem, the surface layer is characterized by a large scale flow pattern of sea ice from the Siberian shelves across the deep basin and towards the North Atlantic through Fram Strait. Below this, the Atlantic Arctic is strongly influenced by the inflow of Atlantic Water (Schauer et al., 2002). This flow occurs in two branches: one across the shallow Barents Sea and one in the deeper Fram Strait to the west and north of Svalbard. The Atlantic Water follows the edges and ridges in the Arctic Ocean influencing all basins but at different depths. It also supplies the region with nutrients and drifting organisms like zooplankton (Kosobokova & Hirche, 2009) and micronekton (Knutsen et al., in press). This advective regime fuels life in the Arctic Ocean (Wassmann et al., 2015; Bluhm et al., 2015).

Over the last three decades, the Atlantic Water has become exceptionally warm, with no analogy since the 1950s or probably in the history of instrumental observations in the Arctic Ocean (Polyakov et al., 2012). In addition, the sea ice cover in the region decreased substantially in both summer and winter (Onarheim et al., 2014). A strong and relatively deep warming over the areas with strongest decay of sea ice in summer has also been observed, with warming up to 3–4°C above the freezing point in the waters that remained ice-free for the longest periods of time.

Production at the lower trophic levels

It is the region's potential with regard to primary and secondary productivity that forms the basis for the production at higher trophic levels. The Arctic Ocean is characterized by stratified water masses and therefore nutrient limitations on biological production exist. This may be an important factor in regulating the planktonic production (e.g., Tremblay and Gagnon, 2009). The inflow of Atlantic water may alter the dynamics of stratification, but the effects of this are largely unknown. With a reduced and thinner sea-ice cover in the Arctic Ocean, the productive period will possibly be prolonged and may result in a moderate increase in total yearly primary production (Slagstad et al., 2011). However, the existing strong vertical stratification limits nutrient availability and is likely to do so in the future (Tremblay and Gagnon, 2009). Hence, the central Arctic Ocean may remain a low production region (Wassmann, 2011). In contrast, along the continental shelf and slope adjacent to the central Arctic Ocean, the productivity response will depend on local to regional conditions. For example, an increased inflow of Atlantic Water will probably enhance sea-ice melt, and a sea-ice reduction beyond the shelf-break will most certainly enhance wind- and ice-forced shelf-break upwelling. This will result in increased solar radiation and nutrient availability, thus increasing productivity (Carmack and McLaughlin, 2011; Tremblay et al., 2011). The Eurasian parameter has been found to have the greatest potential increases in primary production in the future Arctic Ocean (Slagstad et al., 2015). For the time being, large research efforts are being invested in these problems. Also, research on the "Polar night", i.e. production taking place in the dark winter time, is investigated. Results up to now may indicate that there is an accountable production even in winter time(Kraft et al., 2013; Last et al., 2016; Berge et al., 2015). Wassmann et al. (2015) suggests these new results may overthrow our current understanding of the Arctic ecosystems, and, in particular, add uncertainty to how the systems will change in the future.

Ecological knowledge / Ecosystem

Between 2004 and 2013, ecosystems of the Pacific Arctic have changed dramatically (Wood et al., 2015). The leading indicator of this dramatic change is the loss of Arctic sea ice in the summer (Perovich et al., 2013). Changes in the environment due to climate change may occur when resident biological populations respond either positively or negatively to altered timing of events in the annual cycle that coincides with increased temperature, light, and altered sea ice regime (Hopcroft et al., 2008). This ultimately leads to changes in abundance, distribution, and productivity of all trophic levels, which in return leads to changes in the functioning of the ecosystem and the way energy flows in to upper trophic levels such as fish, sea birds, and marine mammals (Hopcroft et al., 2008). Communities of benthic macrofauna on the shallow continental shelves of the Pacific Arctic collect high biomass in response to the high levels of pelagic production advected into the system from upstream primary production (Grebmeier & Maslowski, 2014). These "hotspots" of benthic communities provide prey to other organisms, such as marine mammals and diving seabirds (Grebmeier & Maslowski, 2014).

The most essential attributes of marine ecosystems are their communities associated species composition, along with their specific abundance and biomass (Bluhm, Gradinger, & Hopcroft, 2011). The marine food web of the Pacific Arctic is made up of short linkages that lead from primary productions to humans. The linkages typical of the Arctic ecosystem rely on the underlying biophysical complexity of the system, specifically, processes such as upwelling and lateral transport (Moore & Stabeno, 2015). For species such as marine fishes, birds, and mammals, they must adapt to environmental variability. At broad temporal and spatial scales, snow crabs and fishes seem to be moving north in response to a warmer climate (Moore et al., 2014). When looking at more regional scales, mammals and marine birds have changed features of their body, condition, productivity, and diet as they are responding to the variability in sea ice and prey availability (Moore et al., 2014).

At the Atlantic side of the Arctic Ocean, most of the changes going on may be seen to lead to limited space for Arctic communities when the boreal communities expand northwards. These events are taking place driven by the increased flow of Atlantic water into areas covered by Arctic water only a few years ago. The corresponding movement of boreal species northwards is limited by the northern continental shelf slopes, and the resulting situation seems to be one of limited movement of species into the Central Arctic Ocean. However, Haug et al. (submitted) give a description of possible future harvest development of some commercial species with a potential to move into the open Arctic Ocean. In particular, Greenland halibut, redfish species and northern shrimp are named potential species for northward expansion. Both redfish and capelin may have the largest future potential of northern expansion. As has been mentioned about Polar cod in the other areas, there is large uncertainty as to the response of Polar cod to the future changes here.

As the front of inflowing Atlantic water is changing rapidly on weekly and longer scales, the ecosystems of these front areas are difficult to describe. However, observations of sea mammals along with measurement of large plankton blooms may indicate that production in these front areas may be substantial, and biomass may very well drift into the Central Arctic Ocean with the warm water currents. To what degree these plankton organisms will have multiple annual cycles is unknown.

The position of sea ice is also dependent on the prevailing winds in the areas north of Svalbard, thus making the division between sympagic and boreal habitats very variable, making it difficult to give precise geographical positioning of the types of ecosystems in this area. The area may very well be described as a transition zone between Atlantic and Arctic ecological conditions.

Although the benthic system in the Arctic Ocean is one of large depths, the potential of harvesting bottom dwelling organisms should not be ignored. The benthic system is an integral part of the food web, and changes taking place in the ice-influenced areas of the Arctic affect the biomasses at large depths due to the fact that large portions of the production may sink down in the water masses.

The inlet through the Davis Strait may also be visited by the large stocks of pelagic fish species in the Nordic Seas (herring, capelin, blue whiting and mackerel), and the area of feeding migration for these stocks may include parts of the Arctic Ocean. Their movement would then be closely related to movement of sea mammals utilizing production blooms on various geographical scales.

Historically, marine mammals are known to inhabit large parts of the northernmost waters, and this may well be the situation also in a warming Arctic Ocean. In particular, bowhead whales are endemic species to the Arctic and may benefit from the evolving climatic situation. Falk-Petersen et al. (2014) have pointed to similarities to the period of historic whale hunting in the years 1690 to 1790 and that the present climatic situation may be favorable for the Arctic whales.

Concerning the large stocks of cod-fishes in the Barents Sea, which have been subject to commercial exploitation for centuries and are managed by the Norway – Russia fisheries commission, it is assumed that the cod and haddock are already found at the northernmost border of their distribution. There is, however, a potential for eastwards movement along the shelf bordering the central Arctic Ocean (Hollowed et al., 2013). All together the situation is not one leading to economically profitable fish distributions in the Arctic Ocean, although some visiting by migrating species may occur.

Several fish atlases (Wienerroither et al., 2011) and publications describing changes in distribution of important species in the Atlantic inlet to the Arctic Ocean (Certain and Planque, 2014) have been presented lately.

Tables

Table 1. Species of fish documented to occur within the High Seas area identifying the species with potential for future commercial harvests.

N Species	Binomial	Common name	Potential Future Commercial
1	Anisarchus medius	Stout eelblenny	No
2	Arctogadus glacialis	Arctic cod	**Yes**
3	Artediellus atlanticus	Atlantic hookear sculpin	No
4	Boreogadus saida	Arctic cod	**Yes**
5	Careproctus reinhardti	Sea tadpole	No
6	Cottunculus microps	Polar sculpin	No
7	Liparis fabricii	Gelatinous seasnail	No
8	Lycodes adolfi	Adolf's eelpout	No
9	Lycodes polaris	Canadian eelpout	No
10	Lycodes saggittarius	Archer eelpout	No
11	Lycodes seminudus	Longear eelpout	No
12	Reinhardtius hippoglossoides	Greenland halibut	**Yes**

Source of locality information for species: David et al., 2015; Lin et al., 2012; Mecklenburg, 2015; Melnikov, 1997; Melnikov, I.A., and Chernova, N.V., 2013; Melnikov, I.A., and Chernova, N.V., 2013. Source of commercial potential is the Seafood List.

Table 1.1 Sampling sites for fish species on the High Seas of the central Arctic.

N Species	Binomial	Lat	Long	Common name
1	Anisarchus medius	73.00067 N	-169.00083 W	Stout eelblenny
1	Anisarchus medius	73.99483 N	-168.9875 W	Stout eelblenny
2	Arctogadus glacialis	76.5515 N	-164.4417 W	Arctic cod
2	Arctogadus glacialis	83 N	-177 W	Arctic cod
2	Arctogadus glacialis	87 N	125 W	Arctic cod
2	Arctogadus glacialis	75.33 N	-171.9975 W	Arctic cod
3	Artediellus atlanticus	74.99467 N	-172.03117 W	Atlantic hookear sculpin
4	Boreogadus saida	81.8	-149.69	Polar cod
4	Boreogadus saida	81.43	-142.16	Polar cod
4	Boreogadus saida	74.4839 N	-165.967 W	Polar cod
4	Boreogadus saida	76.5515 N	-164.4417 W	Polar cod
4	Boreogadus saida	81.68 N	129.79 E	Polar cod
4	Boreogadus saida	81.90 N	130.59 E	Polar cod
4	Boreogadus saida	82.91 N	129.76 E	Polar cod
4	Boreogadus saida	83 N	-177 W	Polar cod
4	Boreogadus saida	83.03 N	127.05 E	Polar cod
4	Boreogadus saida	83.06 N	129.76 E	Polar cod
4	Boreogadus saida	84.07 N	30.12 E	Polar cod
4	Boreogadus saida	84.19 N	17.41 E	Polar cod
4	Boreogadus saida	85.16 N	122.59 E	Polar cod
4	Boreogadus saida	87 N	125 W	Polar cod
4	Boreogadus saida	87.42 N	52.90 E	Polar cod
4	Boreogadus saida	87.86 N	60.67 E	Polar cod
4	Boreogadus saida	73.00067 N	-169.00083 W	Polar cod
4	Boreogadus saida	73.99483 N	-168.9875 W	Polar cod
4	Boreogadus saida	74.49767 N	-169.00133 W	Polar cod
4	Boreogadus saida	74.99467 N	-172.03117 W	Polar cod
4	Boreogadus saida	75.33 N	-171.9975 W	Polar cod
5	Careproctus reinhardti	73.99483 N	-168.9875 W	Sea tadpole
5	Careproctus reinhardti	74.99467 N	-172.03117 W	Sea tadpole
6	Cottunculus microps	74.99467 N	-172.03117 W	Polar sculpin
6	Cottunculus microps	75.33 N	-171.9975 W	Polar sculpin
7	Liparis fabricii	83 N	-177 W	Gelatinous seasnail
7	Liparis fabricii	88 N	126 W	Gelatinous seasnail
7	Liparis fabricii	73.99483 N	-168.9875 W	Gelatinous seasnail
7	Liparis fabricii	74.49767 N	-169.00133 W	Gelatinous seasnail
7	Liparis fabricii	75.33 N	-171.9975 W	Gelatinous seasnail
8	Lycodes adolfi	76.5515 N	-164.4417 W	Adolf's eelpout
8	Lycodes adolfi	75.33 N	-171.9975 W	Adolf's eelpout
9	Lycodes polaris	73.99483 N	-168.9875 W	Canadian eelpout
10	Lycodes saggittarius	74.99467 N	-172.03117 W	Archer eelpout
10	Lycodes saggittarius	75.33 N	-171.9975 W	Archer eelpout
11	Lycodes seminudus	76.5515 N	-164.4417 W	Longear eelpout
11	Lycodes seminudus	74.99467 N	-172.03117 W	Longear eelpout
11	Lycodes seminudus	75.33 N	-171.9975 W	Longear eelpout
12	Reinhardtius hippoglossoides	74.99467 N	-172.03117 W	Greenland halibut

References: David et al., 2015, Lin et al., 2012, Mecklenburg et al., 2015, Melnikov, 1997, Melnikov, I.A., and Chernova, N.V., 2012, and Melnikov, I.A., and Chernova, N.V., 2013

Table 1.2. Fish species of documented occurrence in LMEs adjacent to the High Seas in the current version of the FiSCAO database presented in alphabetical order by family and scientific name with common name and status of commercial potential.

Family	Binomial	Common name	Commercial
Acipenseridae	Acipenser baeri stenorhynchus	Siberian sturgeon	Yes
	Acipenser medirostris	Green sturgeon	Yes
	Acipenser sturio	Sturgeon	Yes
Agonidae	Agonus cataphractus	Hooknose	No
	Aspidophoroides monopterygius	Alligator fish	No
	Aspidophoroides olrikii	Arctic alligator fish	No
	Hypsagonus quadricornis	Fourhorn poacher	No
	Leptagonus decagonus	Atlantic poacher	No
	Occella dodecaedron	Bering poacher	No
	Pallasina barbata	Tubenose poacher	No
	Percis japonica	Dragon poacher	No
	Podothecus accipenserinus	Sturgeon poacher	No
	Podothecus veternus	Veteran poacher	No
	Sarritor frenatus	Sawback poacher	No
Alepocephalidae	Alepocephalus agassizii	Agassiz´slickhead	No
Ammodytidae	Ammodytes dubius	Northern sandlance	Yes
	Ammodytes hexapterus	Pacific sand lance	Yes
	Ammodytes marinus	Lesser sandeel	Yes
	Trichodon trichodon	Pacific sandfish	Yes
Anarhichadidae	Anarhichas denticulatus	Northern wolffish	Yes
	Anarhichas lupus	Atlantic catfish	Yes
	Anarhichas minor	Spotted wolfeel	Yes
	Anarhichas orientalis	Bering wolffish	Yes
Anoplopomatidae	Anoplopoma fimbria	Sablefish	Yes
Argentinidae	Argentina silus	Greater argentine	Yes
	Argentina sphyraena	Argentine	Yes
Bathylagidae	Bathylagus euryops	Goiter blacksmelt	No
Belonidae	Belone belone	Garfish	No
Catostomidae	Catostomus catostomus	Longnose sucker	No
Centrolophidae	Schedophilus medusophagus	Cornish blackfish	No
Chimaeridae	Chimaera monstrosa	Rabbit fish	No
Chlamydoselachidae	Chlamydoselachus anguineus	Frilled shark	No
Clupeidae	Alosa agone	Twaite shad	Yes
	Alosa sapidissima	American shad	Yes
	Clupea harengus	Atlantic herring	Yes
	Clupea pallasii	Pacific herring	Yes
	Clupea pallasii suworowi	Chosa herring	Yes

Table 1.2 (cont). Fish species of documented occurrence in LMEs adjacent to the High Seas in the current version of the FiSCAO database presented in alphabetical order by family and scientific name with common name and status of commercial potential. Continued.

Family	Binomial	Common name	Commercial
Cottidae	Artediellus atlanticus	Atlantic hookear sculpin	No
	Artediellus camchaticus	Kamchatkan sculpin	No
	Artediellus gomojunovi	Spinyhook sculpin	No
	Artediellus ochotensis	Okhotsk hookear sculpin	No
	Artediellus pacificus	Hookhorn sculpin	No
	Artediellus scaber	Hamecon	No
	Artediellus uncinatus	Arctic hookear sculpin	No
	Blepsias bilobus	Crested sculpin	No
	Cottus cognatus	Slimy sculpin	No
	Cottus ricei	Spoonhead sculpin	No
	Enophrys diceraus	Antlered sculpin	No
	Enophrys lucasi	Leister sculpin	No
	Eurymen gyrinus	Smoothcheek sculpin	No
	Gymnocanthus galeatus	Armorhead sculpin	No
	Gymnocanthus pistilliger	Threaded sculpin	No
	Gymnocanthus tricuspis	Arctic staghorn sculpin	No
	Hemilepidotus jordani	Yellow Irish lord	No
	Hemilepidotus papilio	Butterfly sculpin	No
	Icelus bicornis	Twohorn sculpin	No
	Icelus spatula	Spatulate sculpin	No
	Icelus spiniger	Thorny sculpin	No
	Icelus spp.	Unknown sculpin	No
	Megalocottus platycephalus	Belligerent sculpin	No
	Micrenophrys lilljeborgii	Norway bullhead	No
	Microcottus sellaris	Brightbelly sculpin	No
	Myoxocephalus jaok	Plain sculpin	No
	Myoxocephalus polyacanthocephalus	Great sculpin	Yes
	Myoxocephalus quadricornis	Fourhorn sculpin	No
	Myoxocephalus scorpioides	Arctic sculpin	No
	Myoxocephalus scorpius	Shorthorn sculpin	No
	Porocottus mednius	Pored sculpin	No
	Porocottus quadrifilis	European plaice	No
	Psychrolutes paradoxus	Tadpole sculpin	No
	Taurulus bubalis	Longspined sculpin	No
	Trichocottus brashnikovi	Hairhead sculpin	No
	Triglops murrayi	Moustache sculpin	No
	Triglops nybelini	Bigeye sculpin	No
	Triglops pingelii	Ribbed sculpin	No
	Triglopsis quadricornis	Fourhorn sculpin	No
Cyclopteridae	Aptocyclus ventricosus	Smooth lumpsucker	No
	Cyclopteropsis jordani	Smooth lumpfish	No
	Cyclopteropsis mcalpini	Arctic lumpsucker	No
	Cyclopterus lumpus	Lumpsucker	No
	Eumicrotremus andriashevi	Pimpled lumpsucker	No
	Eumicrotremus derjugini	Leatherfin lumpsucker	No
	Eumicrotremus orbis	Pacific spiny lumpsucker	No
	Eumicrotremus spinosus	Atlantic spiny lumpsucker	No

Table 1.2 (cont). Fish species of documented occurrence in LMEs adjacent to the High Seas in the current version of the FiSCAO database presented in alphabetical order by family and scientific name with common name and status of commercial potential. Continued.

Family	Binomial	Common name	Commercial
Esocidae	Esox lucius	Northern pike	Yes
Etmopteridae	Etmopterus spinax	Velvet belly	Yes
Gadidae	Arctogadus borisovi	Toothed cod	Yes
	Arctogadus glacialis	Arctic cod	Yes
	Boreogadus saida	Polar cod	Yes
	Eleginus gracilis	Saffron cod	Yes
	Eleginus navaga	Navaga	Yes
	Gadiculus argenteus	Silvery pout	No
	Gadus chalcogrammus	Walleye pollock	Yes
	Gadus macrocephalus	Pacific cod	Yes
	Gadus morhua	Atlantic cod	Yes
	Gadus ogac	Greenland cod	Yes
	Lota lota	Burbot	Yes
	Melanogrammus aeglefinus	Haddock	Yes
	Merlangius merlangus	Whiting	Yes
	Micromesistius poutassou	Blue whiting	Yes
	Pollachius pollachius	European pollock	Yes
	Pollachius virens	Saithe	Yes
	Theragra finmarchica	Norway pollock	Yes
	Trisopterus esmarkii	Norway pout	No
Gasterosteidae	Gasterosteus aculeatus	Threespine stickleback	No
	Pungitius pungitius	Ninespine stickleback	No
Hemitripteridae	Nautichthys pribilovius	Eyeshade sculpin	No
Hexagrammidae	Hexagrammos decagrammus	Kelp greenling	Yes
	Hexagrammos lagocephalus	Rock Greenling	Yes
	Hexagrammos octogrammus	Masked greenling	Yes
	Hexagrammos stelleri	Whitespotted greenling	Yes
	Pleurogrammus monopterygius	Atka mackerel	Yes
Lamindae	Lamna ditropis	Salmon shark	Yes
	Lamna nasus	Porbeagle	Yes
Liparidae	Careproctus derjugini	Deryugin's tadpole	No
	Careproctus dubius	Doubtful snailfish	No
	Careproctus kidoi	Kido's snailfish	No
	Careproctus knipowitschi	Knipowitsch's tadpole	No
	Careproctus longipinnis	Longfin snailfish	No
	Careproctus macrophthalmus	Large-eyed tadpole	No
	Careproctus micropus	Small-eye snailfish	No
	Careproctus phasma	Spectral snailfish	No
	Careproctus ranula	Scotian snailfish	No
	Careproctus reinhardti	Sea tadpole	No
	Careproctus solidus	None	No
	Careproctus spectrum	Stippled snailfish	No
	Careproctus tapirus	Tapir tadpole	No
	Careproctus telescopus	Telescope tadpole	No
	Liparis bathyarcticus	None	No
	Liparis callyodon	Spotted snailfish	No
	Liparis fabricii	Gelatinous seasnail	No
	Liparis gibbus	Variegated snailfish	No
	Liparis liparis	Striped snailfish	No
	Liparis marmoratus	Festive snailfish	No
	Liparis montagui	Montague's snailfish	No
	Liparis ochotensis	Okhotsk snailfish	No
	Liparis tunicatus	Kelp snailfish	No
	Paraliparis bathybius	Black seasnail	No
	Paraliparis violaceus	None	No
	Rhodichthys regina	Threadfin seasnail	No

Table 1.2 (cont). Fish species of documented occurrence in LMEs adjacent to the High Seas in the current version of the FiSCAO database presented in alphabetical order by family and scientific name with common name and status of commercial potential. Continued.

Family	Binomial	Common name	Commercial
Lophiidae	Lophius piscatorius	Angler	Yes
Lotidae	Brosme brosme	Tusk	Yes
	Ciliata mustela	Fivebeard rockling	Yes
	Ciliata septentrionalis	Northern rockling	Yes
	Enchelyopus cimbrius	Fourbeard rockling	Yes
	Gaidropsarus argentatus	Arctic rockling	No
	Gaidropsarus ensis	Threadfin rockling	No
	Molva dipterygia	Blue ling	Yes
	Molva molva	Ling	Yes
Macrouridae	Coelorinchus labiatus	Spearsnouted grenadier	No
	Coryphaenoides rupestris	Roundnose grenadier	Yes
	Macrourus berglax	Roughhead grenadier	No
Merlucciidae	Merluccius merluccius	European hake	Yes
Microstomatidae	Nansenia groenlandica	Large-eyed argentine	No
Myctophidae	Benthosema glaciale	Glacier lantern fish	No
	Lampanyctus macdonaldi	Rakery beaconlamp	No
	Myctophid sp unk	Lanternfish	No
	Notoscopelus kroyeri	Lancet fish	No
	Protomyctophum arcticum	Arctic telescope	No
Osmeridae	Hypomesus olidus	Pond smelt	Yes
	Mallotus catervarius	Pacific capelin	Yes
	Mallotus villosus	Capelin	Yes
	Osmerus dentex	Arctic rainbow smelt	Yes
	Osmerus eperlanus	European smelt	Yes
	Osmerus mordax	Rainbow smelt	Yes
Paralepididae	Arctozenus risso	Spotted barracudina	No
	Paralepis coregonoides	Sharochin barracudina	No
Petromyzontidae	Entosphenus tridentatus	Pacific lamprey	No
	Lethenteron camtschaticum	Arctic lamprey	No
	Petromyzon marinus	Sea lamprey	No
Pholidae	Pholis fasciata	Banded gunnel	No
	Pholis gunnelus	Rock gunnel	No
	Rhodymenichthys dolichogaster	Stippled gunnel	No
Phycidae	Phycis blennoides	Greater forkbeard	No
Pleuronectidae	Atheresthes stomias	Arrowtooth flounder	Yes
	Glyptocephalus cynoglossus	Witch flounder	Yes
	Hippoglossoides elassodon	Flathead sole	Yes
	Hippoglossoides platessoides	Long-rough dab	Yes
	Hippoglossoides robustus	Bering flounder	Yes
	Hippoglossus hippoglossus	Atlantic halibut	Yes
	Hippoglossus stenolepis	Pacific halibut	Yes
	Lepidopsetta bilineata	Rock sole	Yes
	Lepidopsetta polyxystra	Northern rock sole	Yes
	Limanda aspera	Yellowfin sole	Yes
	Limanda limanda	Common dab	Yes
	Limanda proboscidea	Longhead dab	Yes
	Limanda sakhalinensis	Sakhalin sole	Yes
	Liopsetta glacialis	Arctic flounder	Yes
	Microstomus kitt	Lemon sole	Yes
	Platichthys stellatus	Starry flounder	Yes
	Pleuronectes platessa	European plaice	Yes
	Pleuronectes quadrituberculatus	Alaska plaice	Yes
	Reinhardtius hippoglossoides	Greenland halibut	Yes

Table 1.2 (cont). Fish species of documented occurrence in LMEs adjacent to the High Seas in the current version of the FiSCAO database presented in alphabetical order by family and scientific name with common name and status of commercial potential. Continued.

Family	Binomial	Common name	Commercial
Psychrolutidae	Cottunculus microps	Polar sculpin	No
	Cottunculus sadko	Sadko sculpin	No
	Psychrolutes subspinosus	None	No
Rajidae	Amblyraja hyperborea	Arctic skate	Yes
	Amblyraja radiata	Starry skate	Yes
	Bathyraja parmifera	Alaska skate	Yes
	Bathyraja spinicauda	Spinetail ray	Yes
	Dipterus linteus	Sailray	No
	Dipturus batis	Blue skate	No
	Dipturus linteus	Sailray	No
	Dipturus oxyrinchus	Longnosed skate	No
	Leucoraja fullonica	Shagreen skate	No
	Raja clavata	Thornback skate	Yes
	Rajella fyllae	Round ray	No
Salmonidae	Coregonus autumnalis	Arctic cisco	Yes
	Coregonus clupeaformis	Lake whitefish	Yes
	Coregonus laurettae	Bering cisco	Yes
	Coregonus lavaretus	European whitefish	Yes
	Coregonus muksun	Muksun	Yes
	Coregonus nasus	Broad whitefish	Yes
	Coregonus peled	Peled	Yes
	Coregonus pidschian	Humpback whitefish	Yes
	Coregonus sardinella	Least cisco	Yes
	Coregonus tugun tugun	Tugun	Yes
	Oncorhynchus gorbuscha	Pink salmon	Yes
	Oncorhynchus keta	Chum salmon	Yes
	Oncorhynchus kisutch	Coho salmon	Yes
	Oncorhynchus mykiss	Rainbow trout	Yes
	Oncorhynchus nerka	Sockeye salmon	Yes
	Oncorhynchus tshawytscha	Chinook salmon	Yes
	Prosopium cylindraceum	Round whitefish	Yes
	Salmo salar	Atlantic salmon	Yes
	Salmo trutta	Brown trout	Yes
	Salvelinus alpinus	Arctic char	Yes
	Salvelinus andriashevi	Chukot char	Yes
	Salvelinus czerskii	Cherskii's char	Yes
	Salvelinus drjagini	Drjagin's char	Yes
	Salvelinus malma	Dolly varden	Yes
	Salvelinus namaycush	Lake trout	Yes
	Salvelinus taimyricus	Taymyr Lake char	Yes
	Salvelinus taranetzi	Taranetz char	Yes
	Stenodus leucichthys	Inconnu	Yes
	Thymallus arcticus	Arctic grayling	Yes
	Thymallus pallasii	East Siberian grayling	Yes
Scombridae	Scomber scombrus	Atlantic mackerel	Yes
Scopelarchidae	Benthalbella infans	Zugmayer´s pearleye	No
Scophthalmidae	Lepidorhombus whiffiagonis	Megrim	Yes
	Phrynorhombus norvegicus	Norwegian topknot	No
Scorpaenidae	Scorpaenid sp unk	Scorpionfishes	No

Table 1.2 (cont). Fish species of documented occurrence in LMEs adjacent to the High Seas in the current version of the FiSCAO database presented in alphabetical order by family and scientific name with common name and status of commercial potential. Continued.

Family	Binomial	Common name	Commercial
Sebastidae	Sebastes alutus	Pacific ocean perch	Yes
	Sebastes borealis	Shortraker rockfish	Yes
	Sebastes marinus	Golden redfish	Yes
	Sebastes mentella	Beaked redfish	Yes
	Sebastes norvegicus	Golden redfish	Yes
	Sebastes viviparus	Norway redfish	Yes
Somniosidae	Centroscymnus coelolepis	Portugese dogfish	No
	Cetorhinus maximus	Basking shark	Yes
	Galeorhinus galeus	Tope shark	Yes
	Galeus melastomus	Black-mouthed catshark	Yes
	Prionace glauca	Blue shark	Yes
	Somniosus microcephalus	Greenland shark	No
	Somniosus pacificus	Pacific sleeper shark	No
Squalidae	Squalus acanthias	Spiny dogfish	Yes
	Squalus suckleyi	Pacific spiny dogfish	Yes
Sternoptychidae	Agyropelecus hemigymnus	Halfnaked hatchedfish	No
	Argyropelecus olfersi	Olfer's hatchetfish	No
	Maurolicus muelleri	Mueller's pearlside	No
Stichaeidae	Acantholumpenus mackayi	Blackline prickleback	No
	Alectrias alectrolophus	Stone cockscomb	No
	Anisarchus medius	Stout eelblenny	No
	Chirolophis ascanii	Yarrell's blenny	No
	Chirolophis decoratus	Decorated warbonnet	No
	Chirolophis snyderi	Bearded warbonnet	No
	Eumesogrammus praecisus	Fourline snakeblenny	No
	Leptoclinus maculatus	Daubed shanny	No
	Lumpenus fabricii	Slender eelblenny	No
	Lumpenus lampretaeformis	Snakeblenny	No
	Lumpenus maculatus	Daubed shanny	No
	Lumpenus sagitta	Snake prickleback	No
	Stichaeus punctatus	Arctic shanny	No
Stomiidae	Chauliodus macouni	Pacific viper fish	No
Synaphobranchidae	Diastobranchus capensis	basketwork eel	No
Syngnathidae	Entelurus aequoreus	Snake pipefish	No
Trachipteridae	Trachipterus arcticus	Dealfish	No
Triglidae	Eutrigla gurnardus	Grey gurnard	No
Zaproridae	Zaprora silenus	Prowfish	No

Table 1.2 (cont). Fish species of documented occurrence in LMEs adjacent to the High Seas in the current version of the FiSCAO database presented in alphabetical order by family and scientific name with common name and status of commercial potential. Continued.

Family	Binomial	Common name	Commercial
Zoarcidae	Gymnelus andersoni	None	No
	Gymnelus esipovi	None	No
	Gymnelus hemifasciatus	Halfbarred pout	No
	Gymnelus retrodorsalis	Aurora unernak	No
	Gymnelus taeniatus	None	No
	Gymnelus viridis	Fish doctor	No
	Lycenchelys kolthoffi	Checkered wolf eel	No
	Lycenchelys muraena	Moray eelpout	No
	Lycenchelys platyrhina	None	No
	Lycenchelys sarsii	Sars' wolf eel	No
	Lycodes adolfi	Adolf's eelpout	No
	Lycodes brevipes	Shortfin eelpout	No
	Lycodes esmarkii	Esmark's eelpout	No
	Lycodes eudipleurostictus	Doubleline eelpout	No
	Lycodes frigidus	Glacial eelpout	No
	Lycodes gracilis	Common eelpout	No
	Lycodes jugoricus	Shulupaoluk	No
	Lycodes luetkenii	Luetken's eelpout	No
	Lycodes marisalbi	White sea eelpout	No
	Lycodes mcallisteri	McAllister's eelpout	No
	Lycodes mucosus	Saddled eelpout	No
	Lycodes paamiuti	Paamiut eelpout	No
	Lycodes palearis	Wattled eelpout	No
	Lycodes pallidus	Pale eelpout	No
	Lycodes polaris	Canadian eelpout	No
	Lycodes raridens	Marbled eelpout	No
	Lycodes reticulatus	Arctic eelpout	No
	Lycodes rossi	Threespot eelpout	No
	Lycodes saggittarius	Archer eelpout	No
	Lycodes seminudus	Longear eelpout	No
	Lycodes squamiventer	Skjellålebrosme	No
	Lycodes terraenovae	Atlantic eelpout	No
	Lycodes turneri	Polar eelpout	No
	Lycodes vahlii	Vahl's eelpout	No
	Lycodonus flagellicauda	Pointed sole tusk	No

Table 1.2A. Invertebrate species of documented occurrence in LMEs adjacent to the High Seas in the current version of the FiSCAO database presented in alphabetical order by family and scientific name with common name and status of commercial potential.

Family	Binomial	Common name	Commercial
Atelecyclidae	Telmessus cheiragonus	Helmet crab	No
Crangonidae	Sclerocrangon boreas	Sculptured shrimp	No
	Sclerocrangon ferox	Spike shrimp	No
Gonatidae	Berryteuthis magister	Magistrate armhook squid	Yes
Lithodidae	Paralithodes platypus	Blue king crab	Yes
Loliginidae	Doryteuthis pealeii	Longfin squid	No
Oregoniidae	Chionoecetes opilio	Snow crab	Yes
	Hyas araneus	Great spider crab	No
Padiphaeidae	Pasiphaea multidentata	Pink glass shrimp	No
	Pasiphaea sivado	White glass shrimp	No
	Pasiphaea tarda	Crimson pasiphaeid	No
	Pontophilus norvegicus	Norwegian shrimp	No
Pandalidae	Pandalus borealis	Northern shrimp	Yes
Sergestidae	Sergestes arcticus	Panaeid prawn	No
Unknown family	Dendrobranchiata sp unk	Shrimps	No

Table 1.3. Alphabetical List of Fish and Invertebrates Species from Waters Surrounding the High Seas of the Central Arctic in the current version of the FiSCAO database

N Species	Binomial	Common name
1	Acantholumpenus mackayi	Blackline prickleback
2	Acipenser baeri stenorhynchus	Siberian sturgeon
3	Acipenser medirostris	Green sturgeon
4	Acipenser sturio	Sturgeon
5	Agonus cataphractus	Hooknose
6	Agyropelecus hemigymnus	Halfnaked hatchedfish
7	Alectrias alectrolophus	Stone cockscomb
8	Alepocephalus agassizii	Agassiz´slickhead
9	Alosa agone	Twaite shad
10	Alosa sapidissima	American shad
11	Amblyraja hyperborea	Arctic skate
12	Amblyraja radiata	Starry skate
13	Ammodytes dubius	Northern sandlance
14	Ammodytes hexapterus	Pacific sand lance
15	Ammodytes marinus	Lesser sandeel
16	Anarhichas denticulatus	Northern wolffish
17	Anarhichas lupus	Atlantic catfish
18	Anarhichas minor	Spotted wolfeel
19	Anarhichas orientalis	Bering wolffish
20	Anisarchus medius	Stout eelblenny
21	Anoplopoma fimbria	Sablefish
22	Aptocyclus ventricosus	Smooth lumpsucker
23	Arctogadus borisovi	Toothed cod
24	Arctogadus glacialis	Arctic cod
25	Arctozenus risso	White barracudina
26	Argentina silus	Greater argentine
27	Argentina sphyraena	Argentine
28	Argyropelecus olfersi	Olfer's hatchetfish
29	Artediellus atlanticus	Atlantic hookear sculpin
30	Artediellus camchaticus	Kamchatkan sculpin
31	Artediellus gomojunovi	Spinyhook sculpin
32	Artediellus ochotensis	Okhotsk hookear sculpin
33	Artediellus pacificus	Hookhorn sculpin
34	Artediellus scaber	Hamecon
35	Artediellus uncinatus	Arctic hookear sculpin
36	Aspidophoroides monopterygius	Alligator fish
37	Aspidophoroides olrikii	Arctic alligator fish
38	Atheresthes stomias	Arrowtooth flounder
39	Bathylagus euryops	Goiter blacksmelt
40	Bathyraja parmifera	Alaska skate
41	Bathyraja spinicauda	Spinetail ray
42	Belone belone	Garfish
43	Benthalbella infans	Zugmayer´s pearleye
44	Benthosema glaciale	Glacier lantern fish
45	Berryteuthis magister	Magistrate armhook squid
46	Blepsias bilobus	Crested sculpin
47	Boreogadus saida	Polar cod
48	Brosme brosme	Tusk
49	Careproctus derjugini	Deryugin's tadpole
50	Careproctus dubius	Doubtful snailfish

Table 1.3 (cont). Alphabetical List of Fish and Invertebrates Species from Waters Surrounding the High Seas of the Central Arctic. Continued in the current version of the FiSCAO database

N Species	Binomial	Common name
51	Careproctus kidoi	Kido's snailfish
52	Careproctus knipowitschi	Knipowitsch's tadpole
53	Careproctus longipinnis	Longfin snailfish
54	Careproctus macrophthalmus	Large-eyed tadpole
55	Careproctus micropus	Small-eye snailfish
56	Careproctus phasma	Spectral snailfish
57	Careproctus ranula	Scotian snailfish
58	Careproctus reinhardti	Sea tadpole
59	Careproctus solidus	None
60	Careproctus spectrum	Stippled snailfish
61	Careproctus tapirus	Tapir tadpole
62	Careproctus telescopus	Telescope tadpole
63	Catostomus catostomus	Longnose sucker
64	Centroscymnus coelolepis	Portugese dogfish
65	Cetorhinus maximus	Basking shark
66	Chauliodus macouni	Pacific viper fish
67	Chimaera monstrosa	Rabbit fish
68	Chionoecetes opilio	Snow crab
69	Chirolophis ascanii	Yarrell's blenny
70	Chirolophis decoratus	Decorated warbonnet
71	Chirolophis snyderi	Bearded warbonnet
72	Chlamydoselachus anguineus	Frilled shark
73	Ciliata mustela	Fivebeard rockling
74	Ciliata septentrionalis	Northern rockling
75	Clupea harengus	Atlantic herring
76	Clupea harengus	Atlantic herring
77	Clupea pallasii	Pacific herring
78	Clupea pallasii suworowi	Chosa herring
79	Coelorinchus labiatus	Spearsnouted grenadier
80	Coregonus autumnalis	Arctic cisco
81	Coregonus clupeaformis	Lake whitefish
82	Coregonus laurettae	Bering cisco
83	Coregonus lavaretus	European whitefish
84	Coregonus muksun	Muksun
85	Coregonus nasus	Broad whitefish
86	Coregonus peled	Peled
87	Coregonus pidschian	Humpback whitefish
88	Coregonus sardinella	Least cisco
89	Coregonus tugun tugun	Tugun
90	Coryphaenoides rupestris	Roundnose grenadier
91	Cottunculus microps	Polar sculpin
92	Cottunculus microps	Polar sculpin
93	Cottunculus sadko	Sadko sculpin
94	Cottus cognatus	Slimy sculpin
95	Cottus ricei	Spoonhead sculpin
96	Cyclopteropsis jordani	Smooth lumpfish
97	Cyclopteropsis mcalpini	Arctic lumpsucker
98	Cyclopterus lumpus	Lumpsucker
99	Dendrobranchiata sp unk	Shrimps
100	Diastobranchus capensis	basketwork eel

Table 1.3 (cont). Alphabetical List of Fish and Invertebrates Species from Waters Surrounding the High Seas of the Central Arctic in the current version of the FiSCAO database.

N Species	Binomial	Common name
101	Dipterus linteus	Sailray
102	Dipturus batis	Blue skate
103	Dipturus linteus	Sailray
104	Dipturus oxyrinchus	Longnosed skate
105	Doryteuthis pealeii	Longfin squid
106	Eleginus gracilis	Saffron cod
107	Eleginus navaga	Navaga
108	Enchelyopus cimbrius	Fourbeard rockling
109	Enophrys diceraus	Antlered sculpin
110	Enophrys lucasi	Leister sculpin
111	Entelurus aequoreus	Snake pipefish
112	Entosphenus tridentatus	Pacific lamprey
113	Esox lucius	Northern pike
114	Etmopterus spinax	Velvet belly
115	Eumesogrammus praecisus	Fourline snakeblenny
116	Eumicrotremus andriashevi	Pimpled lumpsucker
117	Eumicrotremus derjugini	Leatherfin lumpsucker
118	Eumicrotremus derjugini	Leatherfin lumpsucker
119	Eumicrotremus orbis	Pacific spiny lumpsucker
120	Eumicrotremus spinosus	Atlantic spiny lumpsucker
121	Eurymen gyrinus	Smoothcheek sculpin
122	Eutrigla gurnardus	Grey gurnard
123	Gadiculus argenteus	Silvery pout
124	Gadus chalcogrammus	Walleye pollock
125	Gadus macrocephalus	Pacific cod
126	Gadus morhua	Atlantic cod
127	Gadus morhua	Atlantic cod
128	Gadus ogac	Greenland cod
129	Gaidropsarus argentatus	Arctic rockling
130	Gaidropsarus argentatus	Arctic rockling
131	Gaidropsarus ensis	Threadfin rockling
132	Galeorhinus galeus	Tope shark
133	Galeus melastomus	Black-mouthed catshark
134	Gasterosteus aculeatus	Threespine stickleback
135	Gasterosteus aculeatus	Three-spined stickleback
136	Glyptocephalus cynoglossus	Witch flounder
137	Gymnelus andersoni	None
138	Gymnelus esipovi	None
139	Gymnelus hemifasciatus	Halfbarred pout
140	Gymnelus retrodorsalis	Aurora unernak
141	Gymnelus taeniatus	None
142	Gymnelus viridis	Fish doctor
143	Gymnocanthus galeatus	Armorhead sculpin
144	Gymnocanthus pistilliger	Threaded sculpin
145	Gymnocanthus tricuspis	Arctic staghorn sculpin
146	Hemilepidotus jordani	Yellow Irish lord
147	Hemilepidotus papilio	Butterfly sculpin
148	Hexagrammos decagrammus	Kelp greenling
149	Hexagrammos lagocephalus	Rock Greenling
150	Hexagrammos octogrammus	Masked greenling

Table 1.3 (cont). Alphabetical List of Fish and Invertebrates Species from Waters Surrounding the High Seas of the Central Arctic in the current version of the FiSCAO database. Continued

N Species	Binomial	Common name
151	Hexagrammos stelleri	Whitespotted greenling
152	Hippoglossoides elassodon	Flathead sole
153	Hippoglossoides platessoides	Long-rough dab
154	Hippoglossoides robustus	Bering flounder
155	Hippoglossus hippoglossus	Atlantic halibut
156	Hippoglossus stenolepis	Pacific halibut
157	Hyas araneus	Great spider crab
158	Hypomesus olidus	Pond smelt
159	Hypsagonus quadricornis	Fourhorn poacher
160	Icelus bicornis	Twohorn sculpin
161	Icelus spatula	Spatulate sculpin
162	Icelus spiniger	Thorny sculpin
163	Icelus spp.	Unknown sculpin
164	Lamna ditropis	Salmon shark
165	Lamna nasus	Porbeagle
166	Lampanyctus macdonaldi	Rakery beaconlamp
167	Lepidopsetta bilineata	Rock sole
168	Lepidopsetta polyxystra	Northern rock sole
169	Lepidorhombus whiffiagonis	Megrim
170	Leptagonus decagonus	Atlantic poacher
171	Leptagonus decagonus	Atlantic poacher
172	Leptoclinus maculatus	Daubed shanny
173	Leptoclinus maculatus	Spotted snake blenny
174	Lethenteron camtschaticum	Arctic lamprey
175	Leucoraja fullonica	Shagreen skate
176	Limanda aspera	Yellowfin sole
177	Limanda limanda	Common dab
178	Limanda proboscidea	Longhead dab
179	Limanda sakhalinensis	Sakhalin sole
180	Liopsetta glacialis	Arctic flounder
181	Liopsetta glacialis	Arctic flounder
182	Liparis bathyarcticus	None
183	Liparis callyodon	Spotted snailfish
184	Liparis fabricii	Gelatinous seasnail
185	Liparis gibbus	Variegated snailfish
186	Liparis liparis	Striped snailfish
187	Liparis marmoratus	Festive snailfish
188	Liparis montagui	Montague's snailfish
189	Liparis ochotensis	Okhotsk snailfish
190	Liparis tunicatus	Kelp snailfish
191	Lophius piscatorius	Angler
192	Lota lota	Burbot
193	Lumpenus fabricii	Slender eelblenny
194	Lumpenus lampretaeformis	Snakeblenny
195	Lumpenus maculatus	Daubed shanny
196	Lumpenus sagitta	Snake prickleback
197	Lycenchelys kolthoffi	Checkered wolf eel
198	Lycenchelys muraena	Moray eelpout
199	Lycenchelys platyrhina	None
200	Lycenchelys sarsii	Sars' wolf eel

Table 1.3 (cont). Alphabetical List of Fish and Invertebrates Species from Waters Surrounding the High Seas of the Central Arctic in the current version of the FiSCAO database. Continued

N Species	Binomial	Common name
201	Lycenchelys sarsii	Sars' wolf eel
202	Lycodes adolfi	Adolf's eelpout
203	Lycodes brevipes	Shortfin eelpout
204	Lycodes esmarkii	Esmark's eelpout
205	Lycodes eudipleurostictus	Doubleline eelpout
206	Lycodes frigidus	Glacial eelpout
207	Lycodes gracilis	Common eelpout
208	Lycodes jugoricus	Shulupaoluk
209	Lycodes luetkenii	Luetken's eelpout
210	Lycodes marisalbi	White sea eelpout
211	Lycodes mcallisteri	McAllister's eelpout
212	Lycodes mucosus	Saddled eelpout
213	Lycodes paamiuti	Paamiut eelpout
214	Lycodes palearis	Wattled eelpout
215	Lycodes pallidus	Pale eelpout
216	Lycodes polaris	Canadian eelpout
217	Lycodes raridens	Marbled eelpout
218	Lycodes reticulatus	Arctic eelpout
219	Lycodes rossi	Threespot eelpout
220	Lycodes saggittarius	Archer eelpout
221	Lycodes seminudus	Longear eelpout
222	Lycodes squamiventer	Skjellålebrosme
223	Lycodes terraenovae	Atlantic eelpout
224	Lycodes turneri	Polar eelpout
225	Lycodes vahlii	Vahl's eelpout
226	Lycodonus flagellicauda	Pointed sole tusk
227	Macrourus berglax	Roughhead grenadier
228	Mallotus catervarius	Pacific capelin
229	Mallotus villosus	Capelin
230	Maurolicus muelleri	Mueller's pearlside
231	Megalocottus platycephalus	Belligerent sculpin
232	Melanogrammus aeglefinus	Haddock
233	Merlangius merlangus	Whiting
234	Merluccius merluccius	European hake
235	Micrenophrys lilljeborgii	Norway bullhead
236	Micrfamiliarcottus sellaris	Brightbelly sculpin
237	Micromesistius poutassou	Blue whiting
238	Microstomus kitt	Lemon sole
239	Molva dipterygia	Blue ling
240	Molva molva	Ling
241	Myctophid sp unk	Lanternfish
242	Myoxocephalus jaok	Plain sculpin
243	Myoxocephalus polyacanthocephalus	Great sculpin
244	Myoxocephalus quadricornis	Fourhorn sculpin
245	Myoxocephalus scorpioides	Arctic sculpin
246	Myoxocephalus scorpius	Shorthorn sculpin
247	Nansenia groenlandica	Large-eyed argentine
248	Nautichthys pribilovius	Eyeshade sculpin
249	Notoscopelus kroyeri	Lancet fish
250	Occella dodecaedron	Bering poacher

Table 1.3 (cont). Alphabetical List of Fish and Invertebrates Species from Waters Surrounding the High Seas of the Central Arctic in the current version of the FiSCAO database. Continued

N Species	Binomial	Common name
251	Oncorhynchus gorbuscha	Pink salmon
252	Oncorhynchus keta	Chum salmon
253	Oncorhynchus kisutch	Coho salmon
254	Oncorhynchus mykiss	Rainbow trout
255	Oncorhynchus nerka	Sockeye salmon
256	Oncorhynchus tshawytscha	Chinook salmon
257	Osmerus dentex	Arctic rainbow smelt
258	Osmerus eperlanus	European smelt
259	Osmerus mordax	Rainbow smelt
260	Pallasina barbata	Tubenose poacher
261	Pandalus borealis	Northern shrimp
262	Paralepis coregonoides	Sharochin barracudina
263	Paraliparis bathybius	Black seasnail
264	Paraliparis violaceus	None
265	Paralithodes platypus	Blue king crab
266	Pasiphaea multidentata	Pink glass shrimp
267	Pasiphaea sivado	White glass shrimp
268	Pasiphaea tarda	Crimson pasiphaeid
269	Percis japonica	Dragon poacher
270	Petromyzon marinus	Sea lamprey
271	Pholis fasciata	Banded gunnel
272	Pholis gunnelus	Rock gunnel
273	Phrynorhombus norvegicus	Norwegian topknot
274	Phycis blennoides	Greater forkbeard
275	Platichthys stellatus	Starry flounder
276	Pleurogrammus monopterygius	Atka mackerel
277	Pleuronectes platessa	European plaice
278	Pleuronectes quadrituberculatus	Alaska plaice
279	Podothecus accipenserinus	Sturgeon poacher
280	Podothecus veternus	Veteran poacher
281	Pollachius pollachius	European pollock
282	Pollachius virens	Saithe
283	Pontophilus norvegicus	Norwegian shrimp
284	Porocottus mednius	Pored sculpin
285	Porocottus quadrifilis	European plaice
286	Prionace glauca	Blue shark
287	Prosopium cylindraceum	Round whitefish
288	Protomyctophum arcticum	Arctic telescope
289	Psychrolutes paradoxus	Tadpole sculpin
290	Psychrolutes subspinosus	None
291	Pungitius pungitius	Ninespine stickleback
292	Raja clavata	Thornback skate
293	Rajella fyllae	Round ray
294	Reinhardtius hippoglossoides	Greenland halibut
295	Rhodichthys regina	Threadfin seasnail
296	Rhodymenichthys dolichogaster	Stippled gunnel
297	Salmo salar	Atlantic salmon
298	Salmo trutta	Brown trout
299	Salvelinus alpinus	Arctic char
300	Salvelinus andriashevi	Chukot char

Table 1.3 (cont). Alphabetical List of Fish and Invertebrates Species from Waters Surrounding the High Seas of the Central Arctic in the current version of FiSCAO.

N Species	Binomial	Common name
301	Salvelinus czerskii	Cherskii's char
302	Salvelinus drjagini	Drjagin's char
303	Salvelinus malma	Dolly varden
304	Salvelinus namaycush	Lake trout
305	Salvelinus taimyricus	Taymyr Lake char
306	Salvelinus taranetzi	Taranetz char
307	Sarritor frenatus	Sawback poacher
308	Schedophilus medusophagus	Cornish blackfish
309	Sclerocrangon boreas	Sculptured shrimp
310	Sclerocrangon ferox	Spike shrimp
311	Scomber scombrus	Atlantic mackerel
312	Scorpaenid sp unk	Scorpionfishes
313	Sebastes alutus	Pacific ocean perch
314	Sebastes borealis	Shortraker rockfish
315	Sebastes marinus	Golden redfish
316	Sebastes mentella	Beaked redfish
317	Sebastes norvegicus	Golden redfish
318	Sebastes viviparus	Norway redfish
319	Sergestes arcticus	Panaeid prawn
320	Somniosus microcephalus	Greenland shark
321	Somniosus pacificus	Pacific sleeper shark
322	Squalus acanthias	Spiny dogfish
323	Squalus suckleyi	Pacific spiny dogfish
324	Stenodus leucichthys	Inconnu
325	Stichaeus punctatus	Arctic shanny
326	Taurulus bubalis	Longspined sculpin
327	Telmessus cheiragonus	Helmet crab
328	Theragra finmarchica	Norway pollock
329	Thymallus arcticus	Arctic grayling
330	Thymallus pallasii	East Siberian grayling
331	Trachipterus arcticus	Dealfish
332	Trichocottus brashnikovi	Hairhead sculpin
333	Trichodon trichodon	Pacific sandfish
334	Triglops murrayi	Moustache sculpin
335	Triglops nybelini	Bigeye sculpin
336	Triglops pingelii	Ribbed sculpin
337	Triglopsis quadricornis	Fourhorn sculpin
338	Trisopterus esmarkii	Norway pout
339	Zaprora silenus	Prowfish

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Appendix D: Chairman's Statement on the Fourth Meeting of Scientific Experts on Fish Stocks in the Central Arctic Ocean

The issue of the international management of fisheries in the central Arctic Ocean (CAO) has been addressed at a series of meetings of governments beginning with an initial meeting held in Oslo, Norway in June 2010, and continuing through the most recent meeting of managers held in Iqaluit, Nunavut Territory, Canada in July 2016. Of particular relevance to these meetings has been the interest by the governments in the development of a joint program of scientific research and monitoring to inform future potential fisheries in the CAO. This led to an initial scientific meeting held in Anchorage, AK, USA in June 2011. The general conclusion of that meeting was that there was no urgency, but given the limited scientific knowledge of the CAO there was a need to establish baseline data. Additional scientific meetings were held in Tromsø, Norway (October 2013) and Seattle, USA (April 2015). Participants at these meetings developed a status & gaps report, a partial inventory of research & monitoring, and a draft framework for a Joint Program of Scientific Research & Monitoring.

Government representatives met in Washington, DC, USA in December 2015 to further discuss management of potential CAO fisheries. These participants provided additional guidance on the development of a Joint Program of Research and Monitoring to address the following questions (which represent a refinement of questions raised in the 3rd scientific workshop held in April 2015):

- What are the distributions and abundances of species with a potential for future commercial harvests in the central Arctic Ocean?
- What other information is needed to provide advice necessary for future sustainable harvests of commercial fish stocks and maintenance of dependent ecosystem components?
- What are the likely key ecological linkages between potentially harvestable fish stocks of the central Arctic Ocean and adjacent shelf ecosystems?
- Over the next 10-30 years, what changes in fish populations, dependent species, and the supporting ecosystems may occur in the central Arctic Ocean and the adjacent shelf ecosystems?

To answer these questions, the representatives agreed to three Terms of Reference (ToR) for the fourth scientific meeting:

ToR 1: Complete the synthesis of knowledge
ToR 2: Develop a draft Joint Scientific Research and Monitoring Plan to address the four questions
ToR 3: Provide a Framework for the Implementation Plan

In response to the manager's request, Norway hosted the Fourth Scientific Meeting on CAO Fish Stocks in Tromsø, Norway during 26-28 September 2016. In total, 29 participants attended the meeting representing 10 governments (Canada, People's Republic of China, European Union, the Kingdom of Denmark in respect of Greenland, Iceland, Japan, the Republic of Korea, the Kingdom of Norway, Russian Federation, and United States of America) and interested bodies, including the Arctic Council (PAME/CAFF), PICES, ICES, and the Pacific Arctic Group (PAG). The participating scientists and others were all familiar with Arctic science, surveys and modeling, and the science necessary to support management and conservation of marine living resources.

With respect to ToR1, prior to the meeting, participants collected existing data and analyses of the CAO available from science organizations of the parties. This data call allowed for the completion of the synthesis and integration of analysis of "where we are now" and identified the priorities for research and monitoring gaps. Thus, on Day 1 a draft synthesis report was tabled and discussed. Suggestions for the collection of additional information were provided and will be incorporated into the final draft synthesis report.

The primary objective of the meeting was, however, to focus on developing a Joint Scientific Research and Monitoring Plan (Plan) to address the four questions. A draft version of the Plan was prepared prior to the meeting to elicit discussion. This draft Plan built upon the outcomes of the previous three scientific meetings and considered the need for additional modeling of ecosystem relationships for areas of the CAO with physical and biological data relating to commercial fish species. During the meeting, participants broke into three groups (Mapping and Monitoring, Ecosystem Considerations, Scenarios to deal Climate Changes) to further develop the draft Plan. Meeting participants spent most of Day 2 and the morning of Day 3 in the discussion of these three topics.

Participants at the meeting used the discussion of the Research and Monitoring Plan to develop the list of considerations for implementation of the Plan (ToR3). The desire here was to provide guidance to a 2017 workshop (or workshops) which will develop an implementation strategy for the Plan showing staged development of research and monitoring that addresses gaps in abundance, distribution and other information required to provide advice about the potential for sustainable harvest of commercial species in the CAO.

Meeting participants significantly expanded upon the original draft Plan, and these materials will be combined with materials in the draft Plan to produce a complete draft. This draft Plan will be provided to the meeting's participants for their review by correspondence.

This draft will then be tabled for discussion at the next meeting by the ten governments on management of CAO fisheries scheduled for November 2016 in the Faroe Islands. It will be finalized prior to the 2017 scientific workshop(s) (which will be charged with developing draft Implementation Plans for Research and Monitoring).